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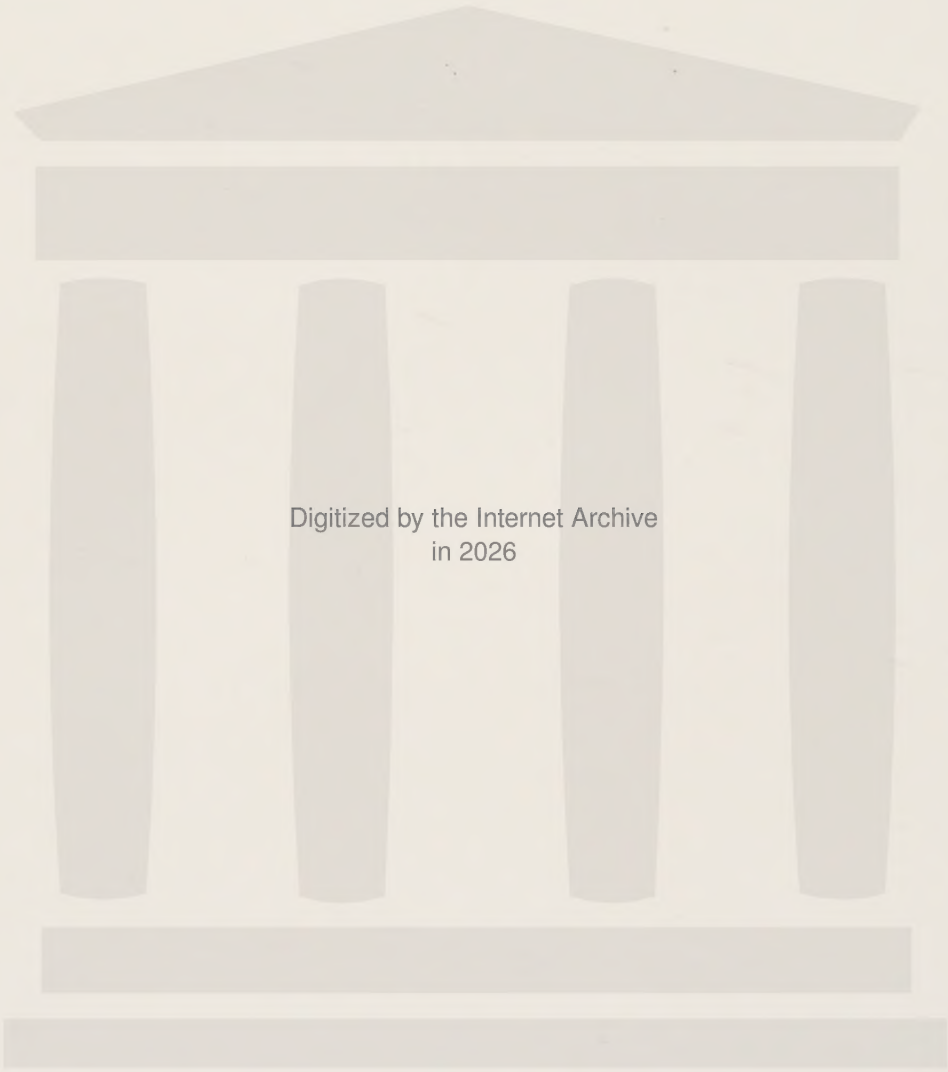
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RESEARCH HIGHLIGHTS 1999•2000

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An annual publication reporting on research of the past calendar year together with a preview of some to be undertaken

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CONTENTS

MISSION OF MARINE AND COASTAL MANAGEMENT

FOREWORD 1

INTRODUCTION 3

STUDIES ON RESOURCES 6
- Pelagic fish 6
- Demersal fish 12
- Linefish 14
- Cephalopods 16
- Abalone 20
- Seaweed 21
- Rock lobster 22

HIGHLIGHTS OF SUPPORTING RESEARCH 26
- Impact of suspended mussel culture on the benthic environment 26
- Near-surface current regimes in the Benguela and southern Angola current systems 27
- Phytoplankton ocean colour and pigment absorption properties 30
- 3-D modelling of pelagic fish recruitment in the Benguela 33
- Acoustic identification of anchovy, sardine and round herring schools 36
- Paralytic shellfish poisoning in abalone *Haliotis midae* on the West Coast 37
- Winter zooplankton in the Angola-Benguela Front region 39
- A two-layer oxygen model for the Elands Bay-St Helena Bay area 41
- Primary productivity of the shelf region off the west coast of southern Africa in winter 42
- Are surveys really necessary to manage our resources? The example of the SA pelagic fishery 43
- Fine-scale spatial trends in the distribution of Agulhas sole 45
- Trends in the sex ratio of Agulhas sole: 1988–1997 46
- Spatial variability in the frequency of mature female Agulhas sole: 1988–1997 47
- Ecosystems approach for pelagic fisheries management: some preliminary results 48
- Performance of demersal fishing gear 51
- Breeding of swift terns 54
- Research in the Southern Ocean 56

TECHNOLOGICAL ADVANCES 61
- New vessel monitoring system for M&CM 61
- Advances in hydro-acoustic research 61

M&CM RESEARCHERS IN THE INTERNATIONAL ARENA 64

PUBLICATIONS 68
- Publications involving staff, directly-contracted staff and seconded staff 68
- Contributions by outside authors 73

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MISSION OF
MARINE & COASTAL MANAGEMENT

To provide for the responsible custodianship of South Africa's marine and coastal resources and ecosystems for the benefit of current and future generations of South Africans. This is achieved by the conservation of such resources and ecosystems through the control of, and the orderly, fair, and equitable access to, their optimum sustainable utilization. Activities are undertaken in accordance with national and international norms, and are

- carried out under the auspices of the Department of Environmental Affairs and Tourism in an open, cooperative and accountable manner, subject to Government policy, and
- based on rigorous, multidisciplinary research and monitoring aimed at developing a comprehensive understanding of relevant resources and ecosystems as well as of relevant industries and communities.

FOREWORD

It is most interesting to see in print and graphically the range and extent of activities carried out with such enthusiasm by scientists of the Department of Environmental Affairs and Tourism. *Research Highlights* include both research aimed at maintaining good management practice in our most important fisheries resources, and that related to resources in the region, such as our participation in the BENEFIT programme and the upcoming and very exciting Benguela Current Large Marine Ecosystem (BCLME) study.

The *Research Highlights*, together with the *South African Journal of Marine Science*, which is rated as the premier journal in its field in Africa, provide excellent showcases for marine science endeavours in this country, and indeed in Southern Africa as a whole. Not only does the Journal provide a barometer of the quality of the science produced, but it gives an opportunity for good work to be publicised locally and in so doing keep our flag flying. The exceptional overall publication record maintained by Marine and Coastal Management scientists, with 130 publications, including 51 refereed articles in the primary scientific literature during 1999 tells the main story. Added to that our scientific staff contributed 43 papers and posters to the 10th Southern African Marine Science Symposium held in 1999. It is also noteworthy that two of our staff, Dr Robert Crawford and Mr Pierre Malan, received the prestigious Gilchrist and Derek Krige Medals respectively.

We greatly desire to see this proud standard being maintained in the future and even developed beyond what has been achieved in recent years. In this regard, we have been aware that marine science at M&CM and elsewhere has come under severe strain, owing both to a decline in funding in real terms and also to the heavy demands being placed on scientists to assist in the transformation of the fishing industry, including some areas for which they are not equipped. In the next year or two we hope to make a contribution to rectifying this situation by stimulating the creation of a new dispensation for marine science in South Africa. This should be aligned with our overall goals to create conditions for the sustainable use of our marine resources.

We hope to see some of the fruits of new research aimed at the ecotourism industry, estuarine research and subsistence fisheries research (a previously sorely neglected area). We also look forward to seeing the refurbished flagship of the research fleet, FRS *Africana*, back in operation and producing results of the calibre that has given South Africa an international reputation for excellence in marine science.

Mohammed Valli Moosa
Minister for Environmental Affairs and Tourism

INTRODUCTION

Once again I have the privilege of writing the introduction to this volume, the last one on this occasion, because I will have left the organization by the time the volume goes to press. Nevertheless, I believe that Marine and Coastal Management (M&CM) can be proud of its scientific achievements in 1999, the year in which it will probably be remembered that the pressures of administrative change in the Department of Environmental Affairs and Tourism took a heavy toll on many of the personnel of M&CM, the biggest Chief Directorate (in terms of number of personnel) in the whole Department. A few key research personnel left to seek challenges elsewhere (some overseas) and those that remained were asked not only to take up the slack left when posts remained unfilled or were cut, but also to broaden their scientific perspectives to address new challenges concomitant with policies on fisheries management contained within the Marine Living Resources Act of 1998. In addition, some research personnel were required to allocate large proportions of their time towards evaluating thousands of applications made for rights within the various fisheries sectors. The latter was necessary simply because of the currently under-resourced nature of the rights-evaluation section of M&CM, but also because it was often the scientific personnel who had first-hand information about both the resources and their fisheries. However, the research input to this crucial task was simply in terms of evaluation according to set criteria, and not decision-orientated, to preclude any suggestion of bias in any aspect of fisheries management advice on behalf of the research personnel.

One of the major challenges to face the research component of both M&CM and the nation in terms of advice during 1999 was to evaluate how and according to what criteria a formally recognized subsistence fishery should be set up for future years. A huge effort was made by the broader marine scientific community in facing this challenge, and many M&CM personnel were involved in various aspects of the evaluation. The task is not yet completely finished, but there is every hope that these fisheries will be managed more efficiently by the beginning of 2001. What this evaluation did offer those privileged to have been part of the exercise was opportunity to interact closely with the many fishers around the coast who until comparatively recently had not even known of the existence of the Department or, in many cases, the Regulations (or the reasons behind them) governing their fishery. Valuable insights were obtained that may well serve the research community positively for several years.

As mentioned in last year's volume, major restructuring of the Department was taking place during 1998, an activity that continued and also had a profound effect on the structures supporting fisheries management at M&CM during 1999, and not just because many posts were lost to M&CM. An agreed structure was implemented in September 1999, but many of the structures were at least partially functioning by then. For the research personnel, this meant that their immediate colleagues in the various directorates became not just other researchers, but also administrative officials dealing with permits and licences, as well as the compliance officials tasked with the difficult function of ensuring that all exploitation of the living marine resources of South Africa was in accord with the Regulations drafted to put into effect the policies of the Marine Living Resources Act. That structure had some advantages, for instance the close integration of the licencing personnel with their first-call advisers, the scientists, but for science *per se*, it came initially as rather a shock. Nevertheless, the structure was made to work by building into it some cross-sectional arrangements, so that scientists were able to benefit from the advice and insights of other scientists when deciding on priority research and when interpreting results. Early in the year 2000, however, a Departmental decision was taken that a further round of

restructuring needed to be considered because of some basic administrative flaws in the previous one. While that restructuring was to take place, the scientific establishment (as well as the control and administrative establishments) were provisionally re-united, so the wheel had turned a full circle within the short period of just 19 months.

During 1999, the tenth in the series of Southern African Marine Science Symposia (SAMSS) was held, and M&CM was represented by a strong contingent of research and technical personnel. Not only did they make a powerful contribution in their own right, but they also made one as members of a 40-strong BENEFIT (BENguela Environment, Fisheries, Interaction and Training) team. BENEFIT, a regional research project of Angola, Namibia and South Africa run under the auspices of the Southern African Development Community (SADC), organized an extensive ship-borne training programme for students from all over southern Africa during 1999. The project was sponsored mainly by the African Development Bank and the World Bank, as well as by the three countries themselves, plus Germany as a major BENEFIT sponsor, and utilized German, Namibian and South African research ships. The results were showcased at the SAMSS meeting, and it was a proud occasion to see all the similarly-dressed BENEFIT researchers (many very new to scientific reporting) making their presence felt among the hundreds at SAMSS. The M&CM poster and verbal presentations were, as usual, of the highest standards.

For the first time for several years, this volume has been edited for two years in succession by the same person, and those who read it will no doubt see an excellent job. In this case, he was also able to count on the assistance of his immediate predecessor, so the two editors did not have to try to exceed their predecessors' performance, only hone their own, something they have achieved admirably. Despite the bureaucratic pressures some scientists may have felt during 1999, the scientific output was still notable, and casual perusal of the pages that follow, specifically but not only relating to the management of the resources, exemplifies that. In particular, I must highlight some of the especially topical and good research carried out by M&CM scientists and their collaborators. For instance, the various in-house initiatives that test the assumptions inherent in acoustic research are world-class, and effort is also being channelled into improving understanding of the output of the swept-area surveys for demersal fish. Valuable knowledge is also being gleaned on the various causes of variability in availability of Agulhas sole *Austroglossus pectoralis*, assisting in improving overall management of that species. Seaweed too, though a minor resource in commercial terms, continues to be researched in a manner that both improves knowledge of commercial species spatially and provides impetus to the development of better utilization techniques.

Most inshore resources are under severe pressure, none more so than the linefish, so it is pleasing to see the sterling efforts that have been made by scientists to institute a Linefish Management Protocol with realistic goals for recovery. Effort has also been put into gaining greater understanding of the single linefish species that is currently in good shape, namely snoek *Thyrsites atun*. In scientific terms too, collaboration with French scientists working locally has led to advances in understanding ecosystem effects on South African commercial fish resources, notably recruitment of pelagic species. In time, that work will no doubt highlight some of the reasons for the current resurgence of anchovy *Engraulis capensis* and the several years of diminished recruitment of sardine *Sardinops sagax*. There has also been notable research output as a result of the window of opportunity afforded environmental researchers to collect data right up the West Coast as far as Luanda, an opportunity given as a result of the international sponsorship of a BENEFIT research training cruise, mentioned above.

From the above, it is easy to exude some optimism for the future – marine science is alive and well in South Africa. Indeed, if one also takes note of the positive outputs from our sister department the Department of Arts, Culture, Science

and Technology, one can easily be lulled into a sense of false security for the future of science as a whole. However, marine science is poised on a knife-edge and could easily fall either way. The loss (and retirement) of some stalwart and key scientists has added pressure to those who remain. The continued struggle for adequate funding and the ageing of the research fleet on which marine science largely depends also give cause for concern. Nevertheless, with enhanced revenue from the users of our living marine resources being made available for fisheries management (including research), with major support from the National Research Foundation and the Department through SANCOR (the South African Network for Coastal and Oceanic Research) promised, and with a new, enthusiastic corps of young scientists starting to make their names in marine science, there is no need for pessimism. The millennium has dawned and with it have come new opportunities that the South African marine science community is poised to take. M&CM will be at the forefront of this challenge, as they have been for many decades already.

Pelagic fish

The anchovy and sardine populations in the southern Benguela continue to show fluctuations in stock size from one year to the next. Stock size is estimated from hydro-acoustic surveys carried out during May/June each year, and during October/November each year. These surveys coincide with peak periods of recruitment of anchovy to the pelagic fishery (May/June, Recruit Survey), and with the peak spawning period of anchovy (October/November, Spawner Biomass Survey).

The number of anchovy recruits during June 1999 was the third highest estimate since the mid-1980s (Fig. 1a). Substantial recruitment had occurred for the third consecutive year and the prognosis for a fair-sized adult population by the end of 1999 was very good. Sardine abundance, however, was very low during June 1999 (Fig. 1b.), and for the first time since 1992 the alternating pattern of good and poor sardine recruitment was broken. Following low recruitment in 1998, no increase in the biomass of the adult population was expected in 1999 (Fig. 1b).

The 16th annual Spawner Biomass Survey undertaken in November 1999 confirmed the results of the Recruit Survey. Three years of good anchovy recruitment enabled the adult biomass to increase above 1 million tons for the first time since 1992 (Fig. 1a). The adult sardine biomass remained virtually unchanged from that measured during 1998 (Fig. 1b). However, two successive years of poor sardine recruitment have reduced the rate of increase in the stock. The adult population

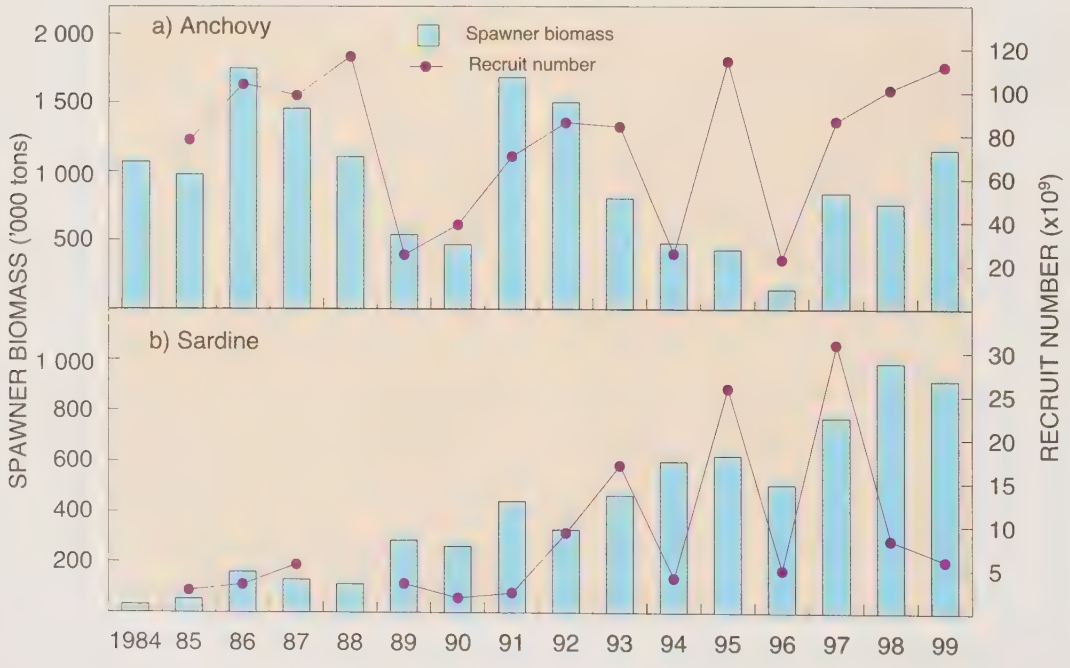

Fig. 1: Time-series of survey results from the Recruit and the Spawner Biomass surveys. Stock sizes at the time of each survey are shown for (a) anchovy and (b) sardine

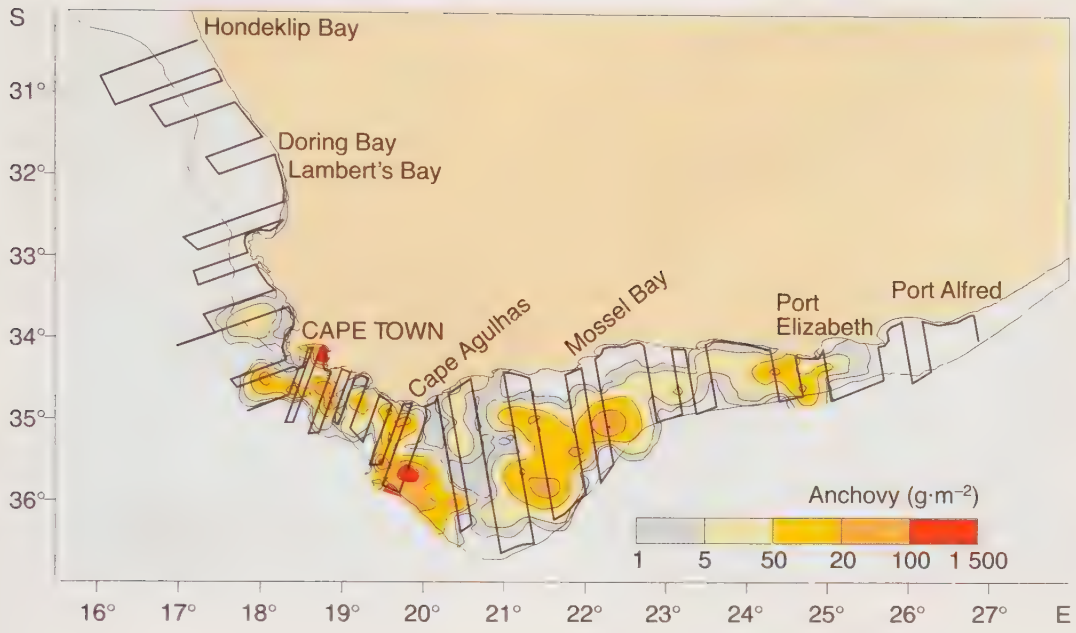

Fig. 2: Distribution and relative abundance of anchovy during the 1999 Spawner Biomass Survey

consisted mostly of older fish from the last good recruitment of 1997.

During the Spawner Biomass Survey, anchovy on the western Agulhas Bank were widespread (Fig. 2). Anchovy were found close inshore in the bays and extended over the entire shelf area, in relatively high densities. Anchovy were more abundant on the western Agulhas Bank than in the previous two years, and the distribution was less patchy. East of Cape Agulhas, the distribution shifted to the mid-shelf area with hardly any anchovy close inshore. Unlike 1998, the distribution did not extend east of Port Elizabeth. It appears that the distribution of anchovy has expanded relative to the increase in the population biomass over recent years.

The distribution of sardine on the West Coast during the Spawner Biomass Survey in 1999 was limited (Fig. 3), compared to the previous two years. By far, the largest part of the sardine population was concentrated in the inshore and mid-shelf areas between Cape Point and Cape Agulhas. Surprisingly, no sardine were found inside False Bay. The distribution of sardine on the South Coast was patchy and similar to the distribution in 1998, with a dense concentration in the mid-shelf area off Cape Infanta, the usual inshore distribution off Mossel Bay, and another dense concentration inside Algoa Bay.

At the end of each year, data from both the Recruit and the Spawner Biomass surveys are used to estimate the recruitment strength of anchovy for that year (referred to as the "model" estimates, see Fig. 4). Recruitment strength is expressed as the total number of recruits at the beginning of the year, and accommodates factors such as natural mortality, fishing mortality and possible bias in survey results. These estimates generally show similar trends to the stock sizes estimated during Spawner Biomass surveys (Fig. 1). For sardine, comparable "model" estimates of recruitment strength are not available. Survey results are used as an indicator of the status of recovery of the stock (Fig. 1).

Forecasts of anchovy and sardine recruitment at the start of each year could play an important

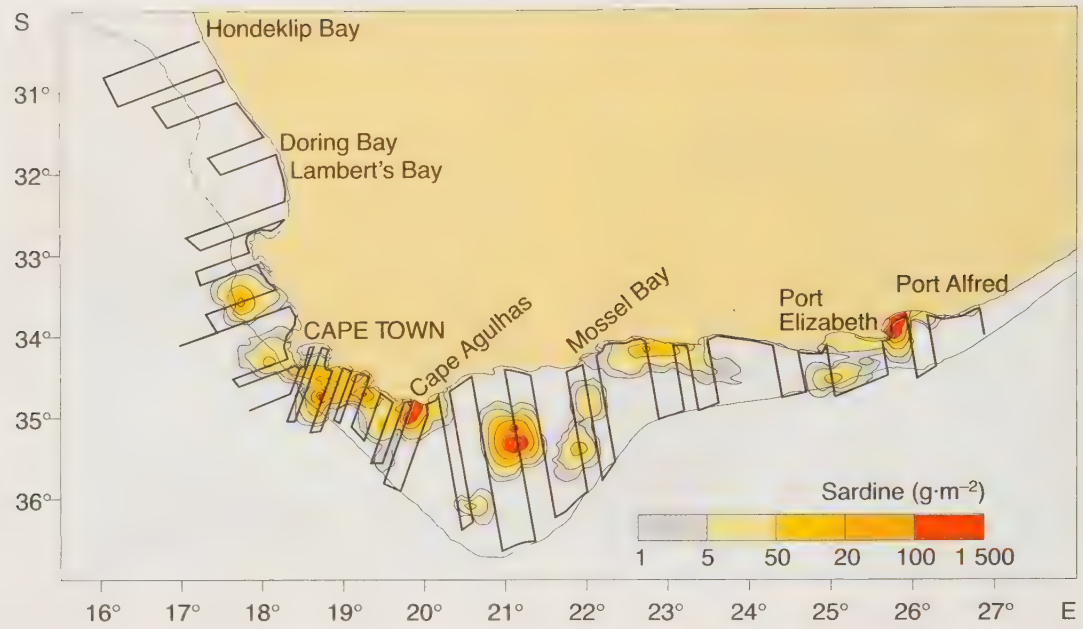

Fig. 3: Distribution and relative abundance of sardine during the 1999 Spawner Biomass Survey

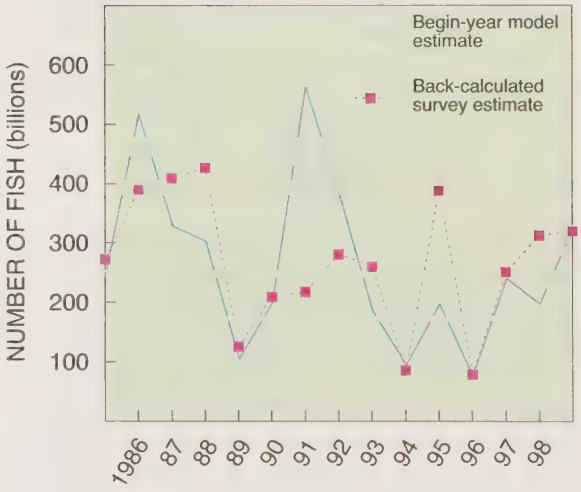

Fig. 4: Time-series of the annual recruitment strength of anchovy, 1985–1999. At the end of each year, data from hydro-acoustic surveys of the recruit and adult densities during that year (done in May/June and October/November respectively) are used to calculate recruitment strength for the year, using a series of models. Begin-year model estimates are compared here with results obtained from back-calculated survey estimates

role in the management of the pelagic fishery. Attempts have recently been made to use surveys of pre-recuit abundances (see below), environmental indices and biological data (see *Research Highlights 1998–1999*) to make these forecasts. However, these studies are still in the developmental phase, and forecasts cannot yet be used in management procedures adapted for the fishery.

Management of the pelagic fishery is dependent on procedures adopted at the beginning of each fishing season, before recruitment strength of anchovy or sardine is known. In recent years, increases in the size of the sardine stock have further complicated the management of the fishery owing to problems of by-catch.

From a survey of pre-recruit abundances in March 1998, the forecast for 1999 was for above-average anchovy recruitment and for average sardine recruitment (see *Research Highlights 1998–1999*). The forecast for anchovy (330 billion begin-year recruits) compared very well with the final estimate of recruitment (326 billion begin-year recruits). The forecast for sardine compared

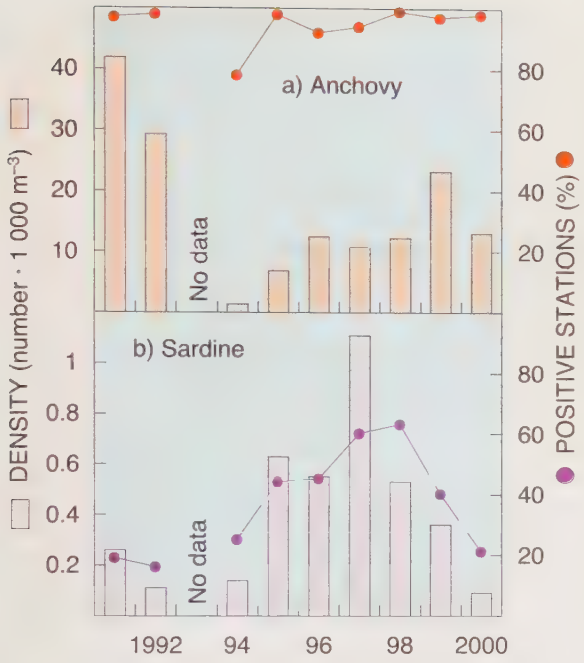

Fig. 5: Time-series of the abundance index (mean density in number·1 000 m^{-3}) and frequency of occurrence (% positive stations) for (a) anchovy and (b) sardine pre-recruits on the West Coast north of Cape Columbine, 1991–2000

less favourably – slightly below-average recruitment was observed during the 1999 Recruit Survey. The results for anchovy demonstrate the potential usefulness of the Pre-Recruit surveys in providing a forecast of recruitment strength sufficiently early during the fishing season to assist management.

Data from the March 2000 Pre-Recruit Survey showed that anchovy pre-recruits were again distributed over the entire West Coast nursery area, being found in 98% of Methot-net samples taken. However, the mean anchovy pre-recuit density of 13 ind.1 000 m^{-3} was significantly lower than observed in 1999 (Fig. 5). Highest densities of anchovy pre-recruits were offshore of the continental shelf west of Cape Columbine (Fig. 6), and consisted predominantly of small (<35 mm total length [*TL*]) pre-recruits. As before, cross-shelf distribution patterns were based on fish size: small pre-recruits were found predominantly offshore of the continental shelf, whereas larger (>35 mm *TL*) pre-recruits were found at low densities over the shelf. Applying the relationship used to predict forthcoming anchovy

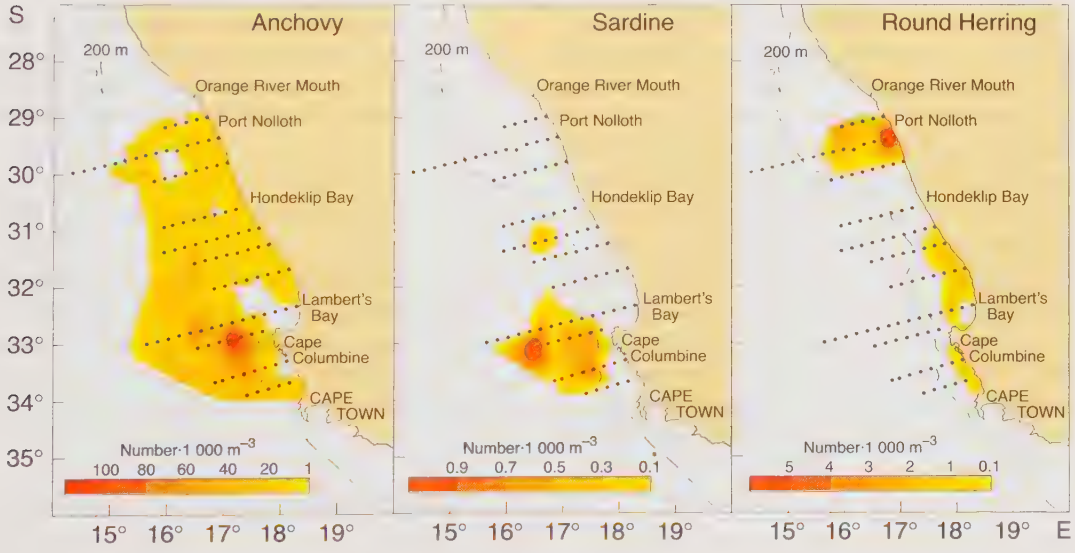

Fig. 6: Distribution and abundance of anchovy, sardine and round herring pre-recruits (shown as number·1 000 m^{-3}) caught by the Methot net during March 2000. The dots indicate positions where samples were collected, and the 200-m depth contour is also shown. Note that the density scales are different for each species

recruitment strength from the mean pre-recruit density (see *Research Highlights 1998–1999*) gives a value of 213 billion begin-year recruits for 2000, which is slightly below the long-term average (1991 to 1997) of 259 billion begin-year recruits.

An unusual feature of the March 2000 survey data was the relatively high density of very large (>60 mm *TL*) anchovy captured by the Methot-net along the inshore and mid-shelf regions between Port Nolloth and Lambert's Bay. Approximately 6% of all anchovy pre-recruits collected this year with the Methot net were larger than 60 mm *TL*. The mean density for this size-class was 0.5 ind·1 000 m^{-3}. This density is the highest yet recorded, for this size-class, during the Pre-Recruit surveys, and may be indicative of successful early spawning in 1999, or exceptionally good environmental conditions that have promoted rapid growth. Owing to their large size and well-developed escape ability compared to smaller fish, it is highly likely that these very large pre-recruits are undersampled by the Methot net, and therefore that their densities are underestimated. Acoustic data collected during the survey indicated a near-continuous distribution of high-density pelagic targets over the continental shelf between Port Nolloth and Lambert's Bay (Fig. 7), which could not be positively identified owing to limitations on trawling. However, it is likely that most of these targets were very large anchovy pre-recruits, some of which were captured by the Methot-net. Both the acoustic and the Methot-net data therefore suggest a substantial area of very large anchovy pre-recruits off the West Coast during March 2000, which is likely to make a positive impact on recruitment. Because these large pre-recruits are undersampled, the recruitment strength predicted from the Methot-derived mean pre-recruit density value may well be an underestimate.

The mean density of sardine pre-recruits (0.09 ind·1 000 m^{-3}) during the March 2000 survey was the lowest yet observed. Sardine were found in 21% of the samples taken (Fig. 5), with a total of only 69 being collected. Pre-recruits were

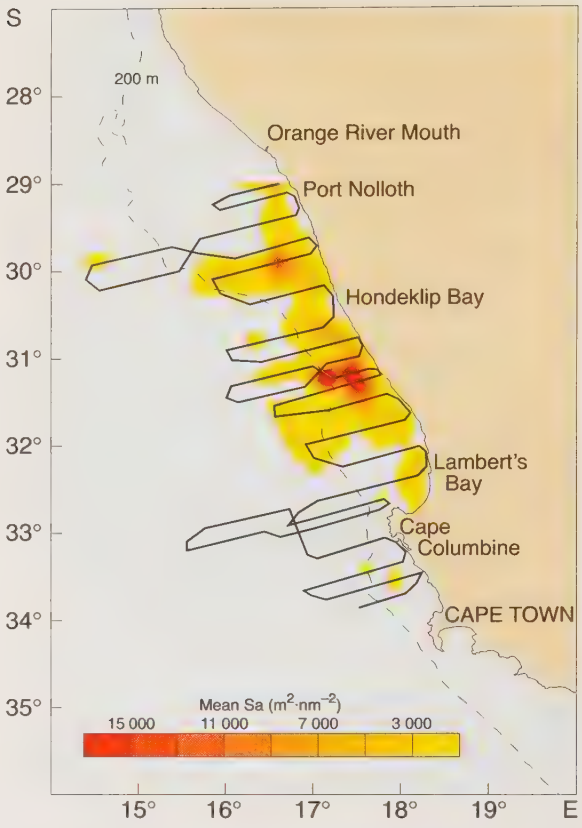

Fig. 7: Acoustically-determined distribution and abundance (shown as back-scattering strength in metres squared per nautical mile squared) of pelagic targets observed during March 2000. The survey track and 200-m depth contour are also shown

predominantly small (<35 mm *TL*), and were located off Cape Columbine together with the high numbers of small anchovy found there (Fig. 6). Applying the relationship between mean sardine pre-recruit density and subsequent recruitment strength measured during the Recruit Survey gives a predicted recruitment strength of 2.17 billion fish, a figure well below the long-term average of 9 billion.

For the first time since the Pre-recruit surveys were initiated in 1991, round herring *Etrumeus whiteheadi* have replaced sardine as the second most commonly encountered pre-recruit species. This is a result of both increasing round herring densities and the sudden decline in sardine

density. Round herring appear to show consistent distribution patterns from year to year, being most frequently encountered in cold, inshore water, and commonly having their highest densities located in the north of the survey region. This conformity in distribution patterns suggests that the inshore and mid-shelf regions off the Orange River mouth are important nursery grounds for this species. With the apparent growth in population size of round herring (not shown), and the likely increase in fishing effort on this species, additional information which will improve our understanding of the life history of the resource can only benefit management.

In 1999 and early 2000, anchovy and sardine continued to be jointly managed by the Operational Management Procedure (OMP) adopted by the Consultative Advisory Forum (CAF) during 1999. There are two new versions of this OMP compared to earlier versions:

- Earlier OMPs made inadequate allowance for the by-catch of juvenile sardines, which is inevitable during anchovy-directed fishing (based largely on juveniles) owing to mixed shoals of the two species, particularly during the early juvenile stages. This problem has become more pronounced over the past few years owing to the general growth of the sardine population, and the subsequent increase in the proportion of juvenile sardine shoaling with anchovy. The current OMP addresses this problem by calculating a more "realistic" allowance for the by-catch of juvenile sardine based on the actual ratio of sardine:anchovy in the commercial fishery during May, and during the May/June hydro-acoustic survey.
- A consequence of the more "realistic" sardine by-catch is that it leads to under-utilization of anchovy. This is because resource productivity is limited, and therefore, if a greater directed catch of (adult) sardine is desired, the size of the juvenile sardine by-catch must be reduced. At present, the only way to achieve this is by reducing the anchovy Total Allowable Catch (*TAC*). However, during August/September, anchovy growth generally slows down and larger sardine separate from the anchovy shoals. There may therefore be a "window of opportunity" from this time to before the anchovy move onto the Agulhas Bank (and away from the fishing grounds) for the fishery to target "clean" anchovy. To counter the under-utilization of anchovy, the current OMP splits anchovy fishing (and its associated sardine by-catch) into two seasons. First there is the "normal" season, which is subject to a "realistic" by-catch as described above. This is followed by a "sub-season" (typically from August/September onwards), which is subject to a low sardine by-catch allowance and an observer scheme to confirm genuinely minimal quantities of juvenile sardine by-catch and an absence of dumping. The sub-season comes into operation only once the normal anchovy season in closed for all participants on a date selected by the CAF (e.g. 31 August). The sub-season allows full utilization of the anchovy resource provided the proportion of juvenile sardine landed with anchovy remains low and does not exceed the set by-catch allowance.

For the sardine-directed fishery, the fishing season is not split into sub-seasons, despite the by-catch allowance (for adult sardine) linked to non-quota species, particularly round herring.

Age determination also plays an important role in the assessment of pelagic fish resources. For sardine, age determinations of fish for the period 1977–1997 were carried out by various age readers with different levels of subject error and/or bias. The need for a unified series of age readings for the period of 1980-present arose in 1997 as a result of an updated OMP. Since 1997 random sub-samples of the collections of sardine otoliths have been re-aged with a unified age determination method. The number of sardine otoliths aged every year exceeds ten thousand. Individual age readings are used to construct age-length keys. These are used to estimate proportions of each year-class per length-class in the annual catch. The annual age compositions serve to assess the contemporary age structure and to determine the annual *TAC*.

Demersal fish

Indices of survey biomass and trends in commercial catch rates of Agulhas sole, used to "tune" the sole stock assessment based on age-structured Virtual Population Analysis (VPA), continued to show conflicting trends in 1999. Previous research has shown that sole catch rates may vary with season (wind strength and direction), depth, sediment type and locality. This information was used to develop an initial General Linear Model (GLM) for standardizing the sole catch per unit effort (*cpue*). However, the preliminary GLM produced a *cpue* trend similar to the series currently being used in assessments. Given that 63% (Fig. 8) of sole-directed drags are made in a small area on the South Coast, from Cape Infanta to Still Bay, the fine-scale spatial movements of the stock away from or into that area in relation to commercial catch rates were investigated. The tentative conclusions, as discussed later, were that the commercial *cpues* were not indices of change in abundance, as these were influenced by the spatial distribution of the stock, irrespective of the estimated biomass. The implications are that, to "tune" the VPA, more reliance should be placed on survey estimates of biomass than on annual trends in commercial catch rates. However, estimates of biomass sometimes plummet on some surveys, the cause of which has not yet been established. In such cases another survey would be necessary to confirm or refute the decline in biomass. Apparent sharp declines in the estimates of biomass in May 1989, September 1990, September 1991 and April 1997 were reversed during subsequent surveys.

The biomass of Agulhas sole, estimated during a survey in April 1999 (Fig. 9a), was 75% of the biomass in 1996, but higher than the low estimate in 1997. Technical problems with the FRS *Africana* in 1998 meant that no biomass estimates were available for that year. During April 1999 the bulk of the stock on the central Agulhas Bank was concentrated around Cape Infanta at depths between 50 and 75 m (Fig. 9a). Plots of mean length per trawl on the central Agulhas Bank (Fig. 9b) showed that the smallest mean lengths of sole were found in two localities: one near Cape Infanta and the other between the Gouritz River mouth and Mossel Bay. Larger mean lengths were found in deeper water. Age-length keys, based on sole otoliths collected during the period 1996–1998, were used to

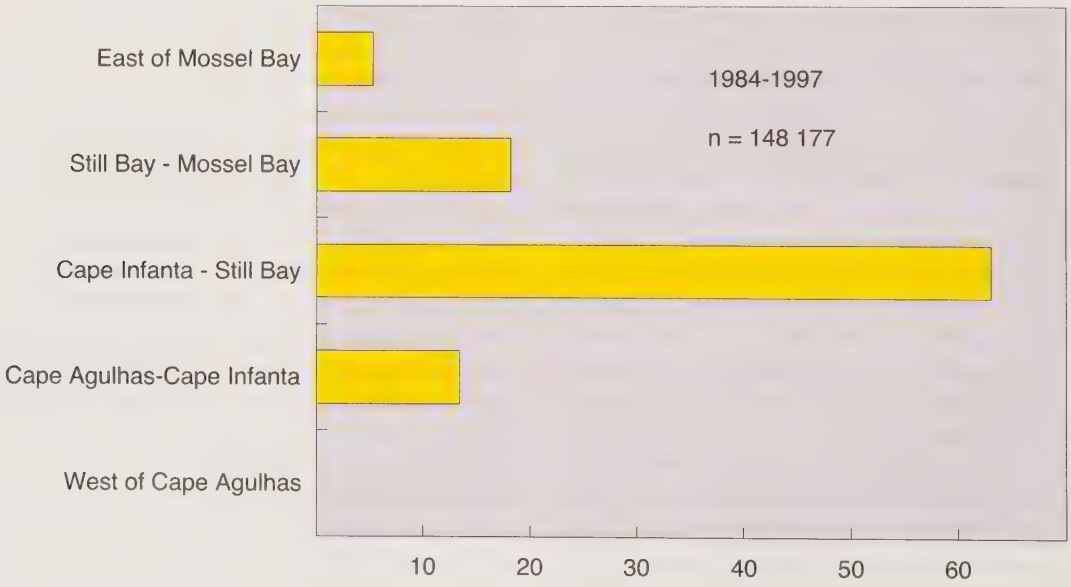

Fig. 8: Percentage of sole-targeted drags on the South Coast during the period 1994–1997

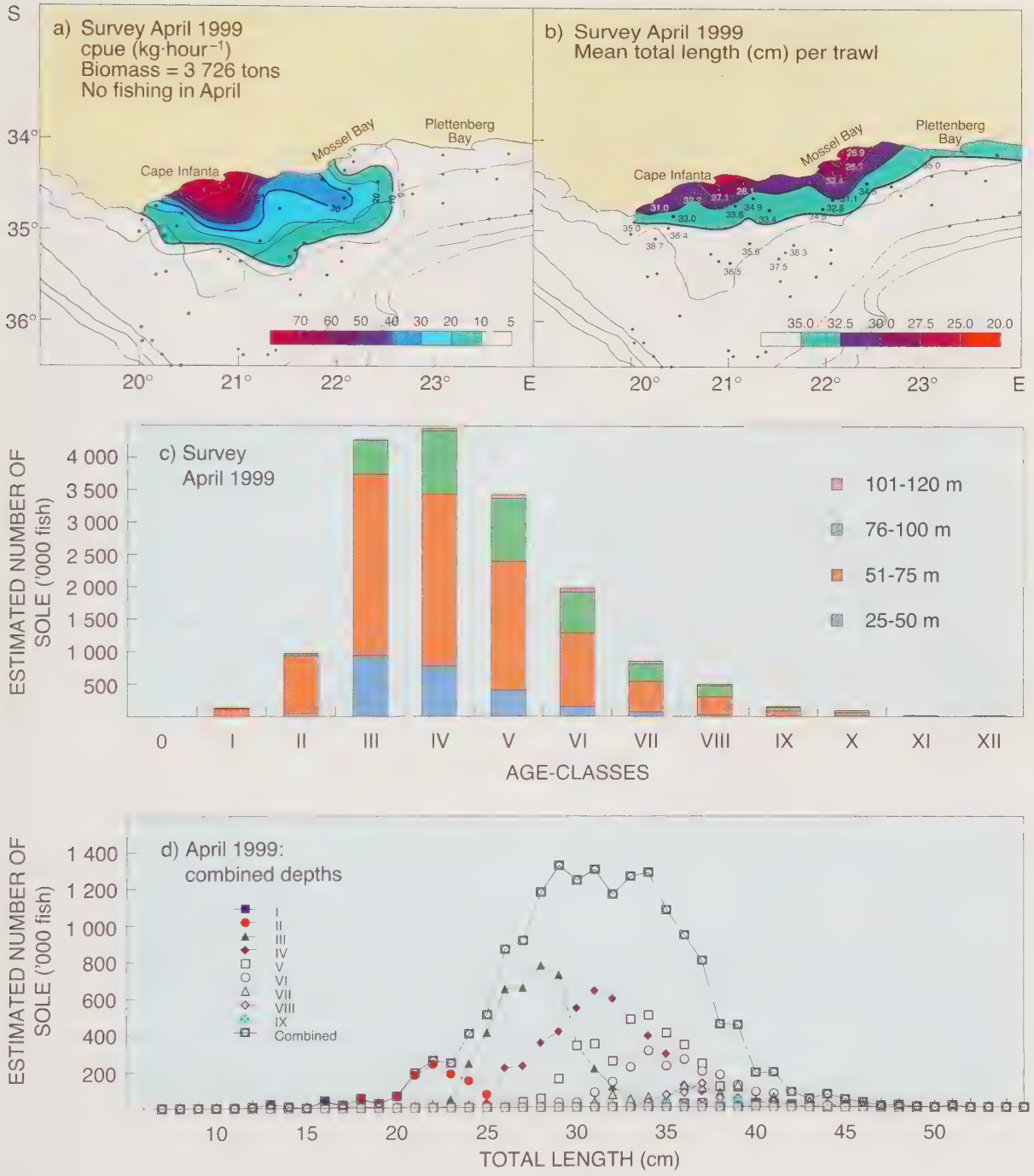

Fig. 9: *(a) Abundance distribution on the central Agulhas Bank, (b) mean length per trawl, (c) age structure per zone and (d) length distribution per age-class of Agulhas sole during April 1999*

determine the age structure of the stock in four depth zones (Fig. 9c). The largest proportion of the fish were found between 51 and 75 m, but, since the sole are not randomly distributed, the absence of trawls in the shallow water (<50 m) near Cape Infanta may have skewed the results. The length distributions per age-class of Agulhas sole are shown in relation to the length distribution of the stock in April 1999 (Fig. 9d). Age-classes III to VI comprise the bulk of the stock captured during the survey. The younger fish are not captured in deeper water and generally there are few older fish.

Linefish

Implementation of the new Linefish Management Protocol (LMP) is proceeding well. A scientific workshop was held in September 1999 to review current management regulations for linefish in the light of the LMP. Most linefish were found to be overexploited and Regulations in many cases were inappropriate. Draft management plans (including amended Regulations) have subsequently been developed for 22 important linefish species. These draft management plans will be further discussed with user groups at a workshop of the South African Marine Linefish Management Association in June 2000. The recommendations emanating from the two workshops will be submitted via the CAF to the Minister of Environmental Affairs and Tourism.

Snoek *Thyrsites atun* has been an important commercial species in the Benguela ecosystem since the early 1800s; caught initially with handlines it has also been trawled since 1960. Total annual catch peaked at about 81 000 tons in 1978, but dropped substantially with the exclusion of foreign trawlers from the Namibian fishing grounds in 1991. Current annual catch ranges between 14 437 and 22 920 tons (1991–1995), with 93% of it made in South African waters. *T. atun* is by far the most important species caught by the South African commercial linefishery (comprising 39% of the 1986–1997 catch). Around 40% of the South African catch is made by commercial handline fishers and 60% by trawlers. In addition to its fishery significance, *T. atun* is one of the major predators of anchovy and sardine in the southern Benguela ecosystem.

A study of the life history of South African snoek was initiated in 1995 with a view to improving management advice for this important resource. Benguela *T. atun* apparently comprise two separate sub-populations – one off Namibia and the other off South Africa – with medium-term (c. 5 years) exchange in response to environmental events and food availability. South African *T. atun* attain 50% sexual maturity at a fork length of c. 72.5 cm (3 years). Spawning occurs offshore, along the shelf break (150–400 m) of the western Agulhas Bank and the South African west coast (Fig. 10) during winter-spring, when most of the trawl catch is made. Prevailing currents transport eggs and larvae to a productive nursery ground north of Cape Columbine and to a secondary nursery area to the east of Danger Point; both shallower than 150 m. Juveniles remain on the nursery grounds until maturity, growing to between 33 and 44 cm in the first year (3.25 $cm \cdot month^{-1}$). Onshore-offshore movements of juveniles (between the 5 and 150-m isobaths) are determined largely by prey availability and include a seasonal onshore migration in autumn in response to clupeoid recuitment. As a result, handline catches of juvenile or "china" snoek escalate dramatically in the St Helena Bay area at this time of year. Adults are found throughout the distribution range of the species, and although they move offshore to spawn, longshore movement is random and without a seasonal basis. Males spend more time on the spawning grounds than do females, consequently females comprise most of the handline catch and males most of the trawl catch during winter-spring.

A three-year programme to evaluate participation in, and management of, the beach-seine and gill-net fisheries on the West and South-West coasts has recently been completed. The programme included a detailed socio-economic survey, monitoring of catches and fishery-independent experimental netting.

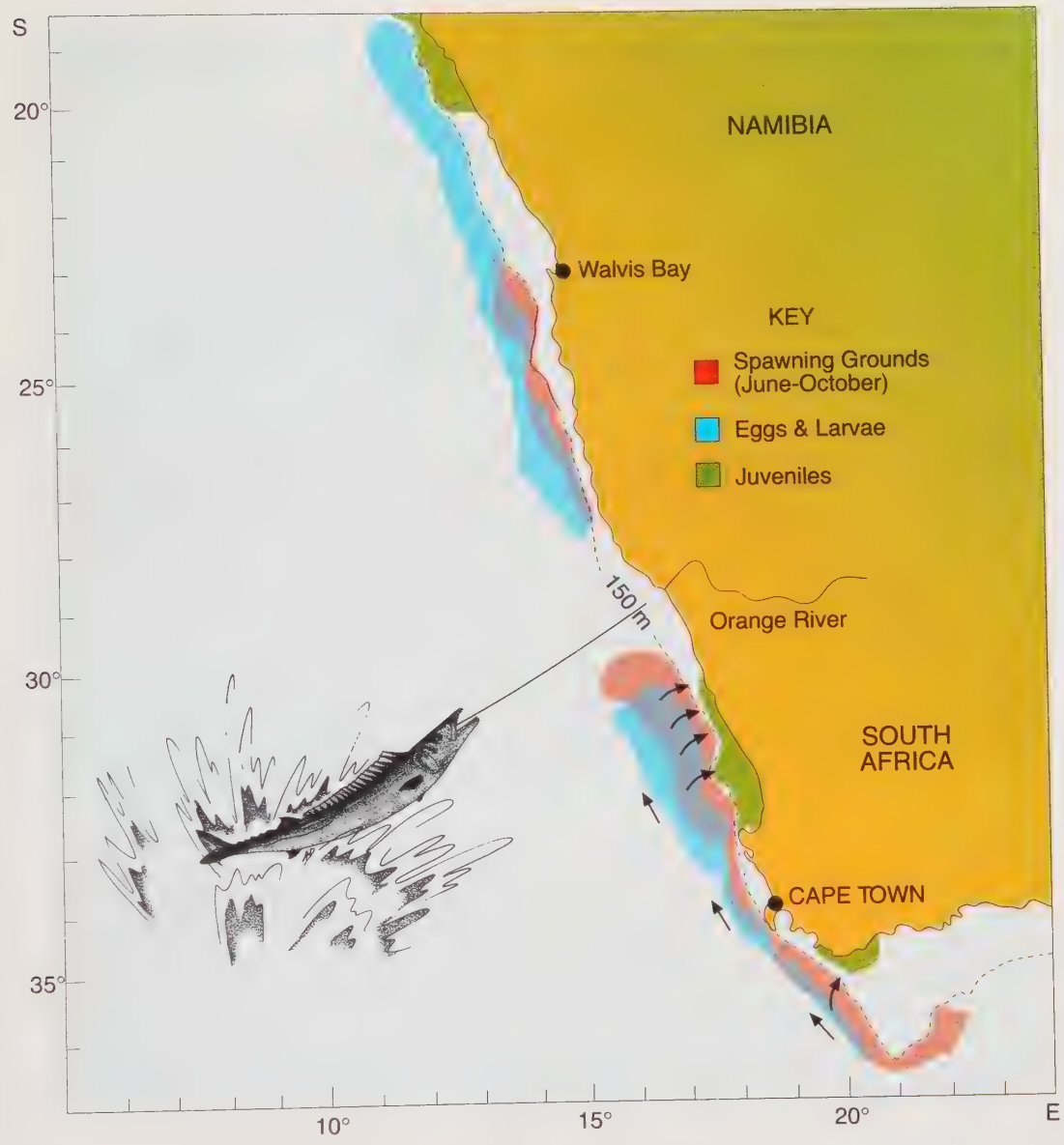

Fig. 10: Conceptual model depicting the life history of Benguela snoek

Catch monitoring and interviews of fishers have allowed a reasonable estimate of total catch to be made. Annual effort in the commercial gill-net fishery was estimated at 28 000 trips with an estimated yield of 2 750–3 250 tons of harders, 650 tons of St Joseph shark and 130 tons of by-catch comprising at least 27 species. Maasbanker, elf, gurnard, galjoen, white stump and steentjie dominated the by-catch. The illegal gill-net fishery is responsible for at least another 1 800 net-days each year catching in the region of 100 tons of houndshark and 50 tons of linefish, mostly galjoen. Beach-seine permit-holders make approximately 3 300 hauls per year catching 1 850–1 950 tons harders and 200 tons by-catch. Thus, the total mass of fish caught annually by the combined beach-seine and gill-net fisheries is approximately 6 000 tons which is substantially more

than the annual reported catch of 1 369 tons. Comparison of monitored catch and effort with that submitted on catch return forms suggests that only 20% of effort and 8% of the catch are reported. Harders aside, only 3% of the by-catch, mostly linefish, is reported.

The majority of permit-holders interviewed had other occupations. Two-thirds of the net-fishers interviewed were involved in some other form of fishing, mostly in the pelagic industry. Few (11%) regarded net-fishing as their primary source of income. Occupations listed included farmers, navy personnel, teachers, builders and State employees. With the exception of Saldanha Bay and Langebaan, 60% of interviewees claimed to make less than 5% of their income from net-fishing. These claims are supported by the calculation that the average net-fishing operation is running at an annual loss of R2 000. The general consensus amongst net-fishers was that net-fishing as a sole source of income was not economically viable owing to decreased catch rates, low and sporadic availability of fish and increased costs, particularly of fuel, in recent years.

Cephalopods

During 1999 the fishery for chokka squid, *Loligo vulgaris reynaudi*, in South Africa was restructured. All existing permits were revoked and new applications called for. There were over 450 applications received for at least 3 600 fishers. Permits were awarded to 2 324 fishers, keeping effort at a constant level when compared with that prior to restructuring. However, modelling of risk associated with the present level of effort indicated that the present effort must be reduced by at least 10%, but preferably by as much as 30%. This resource is particularly vulnerable to the "creeping effort increase", which is a hidden form of increased efficiency where more chokka is landed with the same number of permits.

Research on cephalopods has continued on three fronts: stock assessment and management; forecasting of abundance, distribution and availability using biological and environmental measurements; and biological research in support of management.

Research on management focussed mainly on the future of the closed season, ways of measuring effort in the jig fishery, and reliability of the *cpue* data. Forecasting research focussed on investigating the dynamics of benthic turbidity events and their impact on the fishery.

Although the chokka fishery is relatively young, yearly squid catches have been highly erratic. These fluctuations have been ascribed to large environmental and oceanographic variability along the South Coast. Studies undertaken to date indicate that turbidity is the single most important parameter negatively affecting the behaviour of spawning chokka squid. Near-bottom turbidity owing to suspension of particulate matter in the water column results in reduced underwater visibility. An experiment currently underway in Kromme Bay (St Francis Bay), the central region of the squid spawning grounds, is designed to understand the dynamics, characteristics, causes and impacts of benthic turbidity events on the spawning grounds along the South African south coast. Climatic (wind strength and direction) and oceanographic (currents, temperature and wave height) conditions are believed to be the driving forces of these events, forming complex interactions with each other. Two surveys on board the FRS *Africana* between Cape Agulhas and Port Alfred on the eastern Agulhas Bank were conducted in 1999 to monitor the vertical and horizontal distribution of turbidity events using Optical Back-scatter (OBS) turbidity sensors. Two observations were made at 25 m and a further observation at 7 m in Kromme Bay. Turbidity events appeared to take place predominantly in the inshore zone, and where they were observed further offshore, they were less intense and less frequent. Correlation of turbidity readings with an onboard temperature sensor shows that events take place during upwelling as well as in isothermal conditions. Correlation between downwelling and turbidity is apparent in deeper waters (Fig. 11).

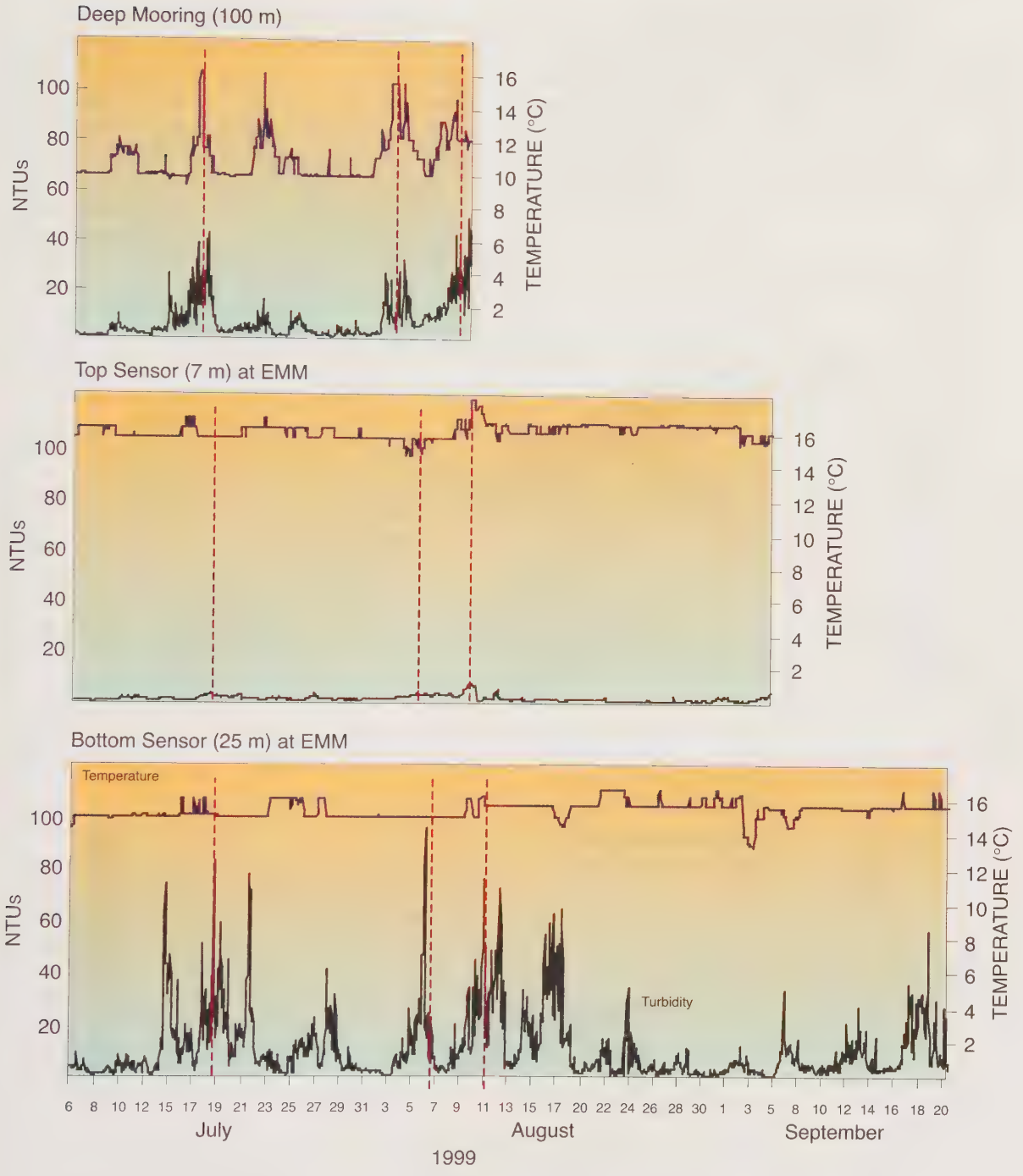
Deep Mooring (100 m)
NTUs
TEMPERATURE (°C)
Top Sensor (7 m) at EMM
Bottom Sensor (25 m) at EMM
Temperature
Turbidity
6 8 10 12 15 17 19 21 23 25 27 29 31 3 5 7 9 11 13 15 17 20 22 24 26 28 30 1 3 5 8 10 12 14 16 18 20
July
August
September
1999

Fig. 11: Turbidity reading from OBS sensors at the Deep Mooring (100 m sounding) and Environmental Monitoring Mooring (EMM) in Kromme Bay with corresponding temperature from onboard sensor: July – September 1999

An Acoustic Doppler Current Profiler (ADCP) and Wave Height Recorder (WHR) deployed near the OBS sensors provide environmental information. Although data captured by the above instruments will only be available upon their retrieval, it can already be noted that turbidity events coincide with increased wave activity.

It was previously thought that turbidity events are restricted to sheltered regions of the coastline. Fixed transects were monitored in the "sheltered" Kromme Bay and the more exposed coastline in the vicinity, using a portable Conductivity-Temperature-Depth (CTD) recorder equipped with a turbidity sensor, to determine the long-shore distribution of the events. The CTD transects confirm results of shipboard surveys and provide an opportunity for in-depth studies of any events between the permanent moorings in Kromme Bay. Results thus far indicate that turbidity events occur in all areas of the inshore

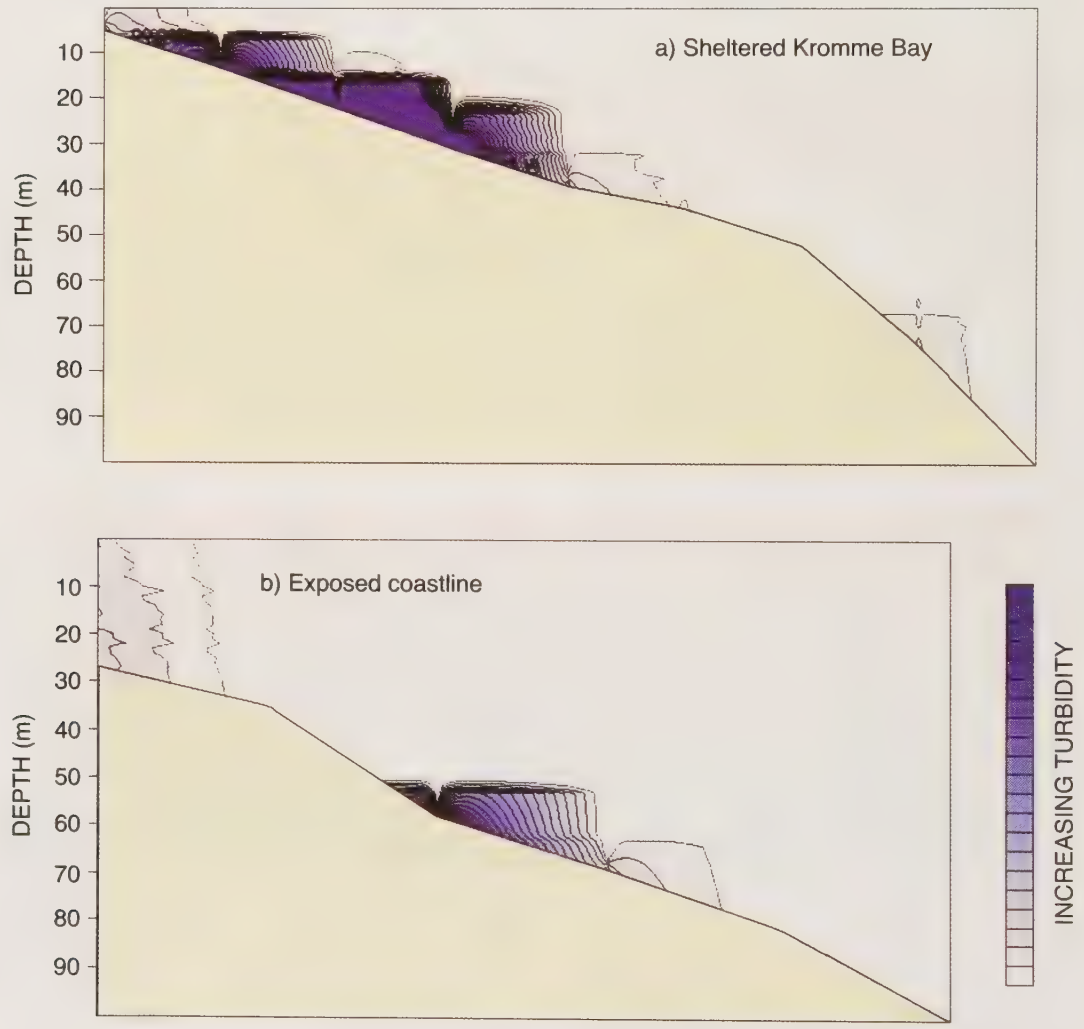

Fig. 12: CTD transects running offshore to a 100-m sounding in two regions of Kromme Bay, namely (a) the sheltered bay itself and (b) a more exposed nearby coastline. Turbidity is most extensive in the inshore areas of both regions

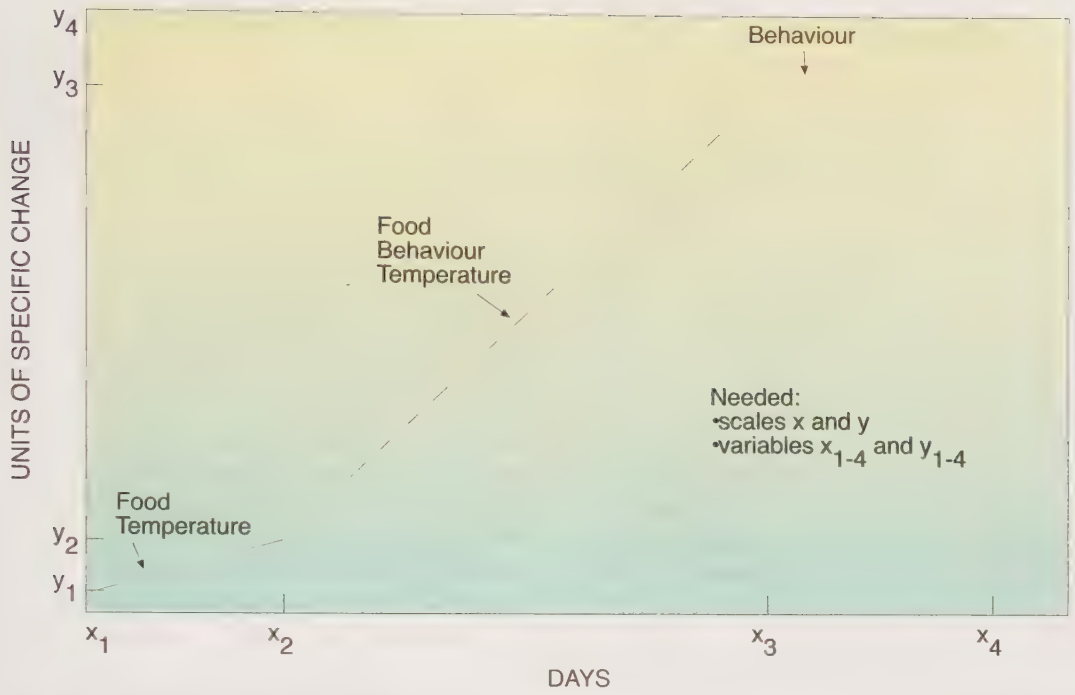

Fig. 13: Graphic representation of the basic growth model of cephalopods. Water temperature, food availability and behaviour determine the length and slope of each of the three stages of the model. Scales x (number of days) and y (units of specific change) and variables x_{1-4} and y_{1-4} are needed to describe growth of any cephalopod

spawning grounds, in sheltered bays and exposed coastlines, diminishing as they extend offshore, and do not extend to surface waters (Fig. 12).

It is clear that the driving forces, acting individually or in concert, cause benthic turbidity events to take place in all regions of the squid spawning grounds. This ongoing study, which involves monitoring of turbidity, waves, temperature, currents and squid catches, forms an integral part of a much larger model incorporating climate, oceanography and biology in the management of the chokka fishery.

Biological research in support of management was rather diverse and focussed on a number of ongoing projects. Research on squid reproduction focussed on the duration of the spawning period and the estimation of the spawning fraction. The latter was derived from the number of eggs in the oviducts collected over a period of 24 hours. Data obtained in this study provide the first estimate of spawning fraction of its kind. The results may assist the modelling of optimal duration and timing of the closed season as well as the construction of a general model of chokka exploitation.

A general model of cephalopod growth was presented at a conference on "Cephalopods – Present and Past" held in Vienna. This model was based on evidence gathered from observations whilst maintaining cephalopods in aquaria as well as from statolith research. Data suggest that cephalopod growth may be described by three linear equations, representing paralarval, juvenile+adult and spawning phases in the life cycle of squid (Fig. 13). Understanding cephalopod growth is important in estimating parameters used in the stock assessment of this resource.

Ageing of chokka continued mainly under a

project assessing the beneficial role of the closed season. If particularly numerous age-classes can be traced to the closed season by back-calculating the hatching and spawning times, then the role of the closed season can be more precisely determined and quantified. This research is to continue in the year 2000.

Physiological research continued in three basic directions. Biomineralization studies seek independent confirmation (validation) of squid age readings. Immunological studies are aimed at the development of the stress level scale, which may be important in the forecasting and behavioural projections. Studies on food and feeding of paralarvae resulted in the development and publication of an immunoassay method for the detection and identification of multiple paralarval prey items.

Abalone

The period of 1999–2000 proved a difficult one in which to fulfill all abalone research and monitoring obligations, because of unexpected constraints placed on internal financial administration mechanisms. Fishery-Independent Abalone Surveys (FIAS) could not be completed in two of the four major zones, therefore this data series is now incomplete. Recruitment monitoring was not carried out owing to the priority assigned to FIAS work. In addition, no monitoring of the ecological changes within the kelp forests east of Cape Hangklip was possible. Lobsters remain abundant between Cape Hangklip and Hermanus, and predation in these areas has removed virtually entire populations of small edible invertebrates such as sea urchins, whelks and winkles, which provide shelter for abalone recruits.

No contract could be awarded for the telephonic polling of recreational fishers, therefore no data will be available for the 1999/2000 season. Past surveys have shown that curtailing the available diving days to weekends and public holidays only, was successful in achieving a reduction in recreational landings. Landings declined from past levels of around 500 tons to 127 tons, the lowest level since the inception of the telephonic surveys. The causes of the decline in landings were primarily the tenfold reduction in available diving days (Fig. 14a), and the concomitant drop in the number of permits sold, from about 35 000 to <15 000.

Age-structured production models, fitted to the *cpue* data, are being developed to reconstruct the history of the resource dynamics. The effects of various changes in the fishery structure are being addressed through generalized linear modelling.

Paralytic Shellfish Poisoning or PSP toxins were found in abalone on the West Coast and Robben Island for the first time in South Africa, during 1999. Although the source of the toxins is still unknown, some abalone were found to have PSP toxicity levels high enough to cause severe illness if consumed (see later). Resource managers responded to the PSP observations by closing both the recreational and commercial fisheries in these areas. Subsequent to further sampling and testing the fisheries were re-opened subject to an advisory warning.

Poaching continues to decimate the abalone resource. Efforts to quantify this sector, and thereby its impact on the resource, continue through monitoring of confiscation and arrest records. In addition, direct estimation of poaching was attempted by aerial observation of poachers from a chartered light aircraft, from June 1997 to January 2000. Randomly-scheduled flights were carried out along the coastline from Cape Hangklip to Quoin Point, and observations of visible poaching groups were made. Calculated estimates of poaching based on these observations were unrealistically low, less than 100 000 abalone per annum, which is less than the reported confiscation records. However, the data did show that, probably owing to poaching-induced decimation of the resource in Zone C (Hawston – Hermanus), poachers began moving from Zone C to Zone A (Buffeljags area) in mid-1998. A reduction in visible poaching activity during the compliance exercise Operation Neptune early in 1999 indicated the effectiveness of such exercises (Fig. 14b).

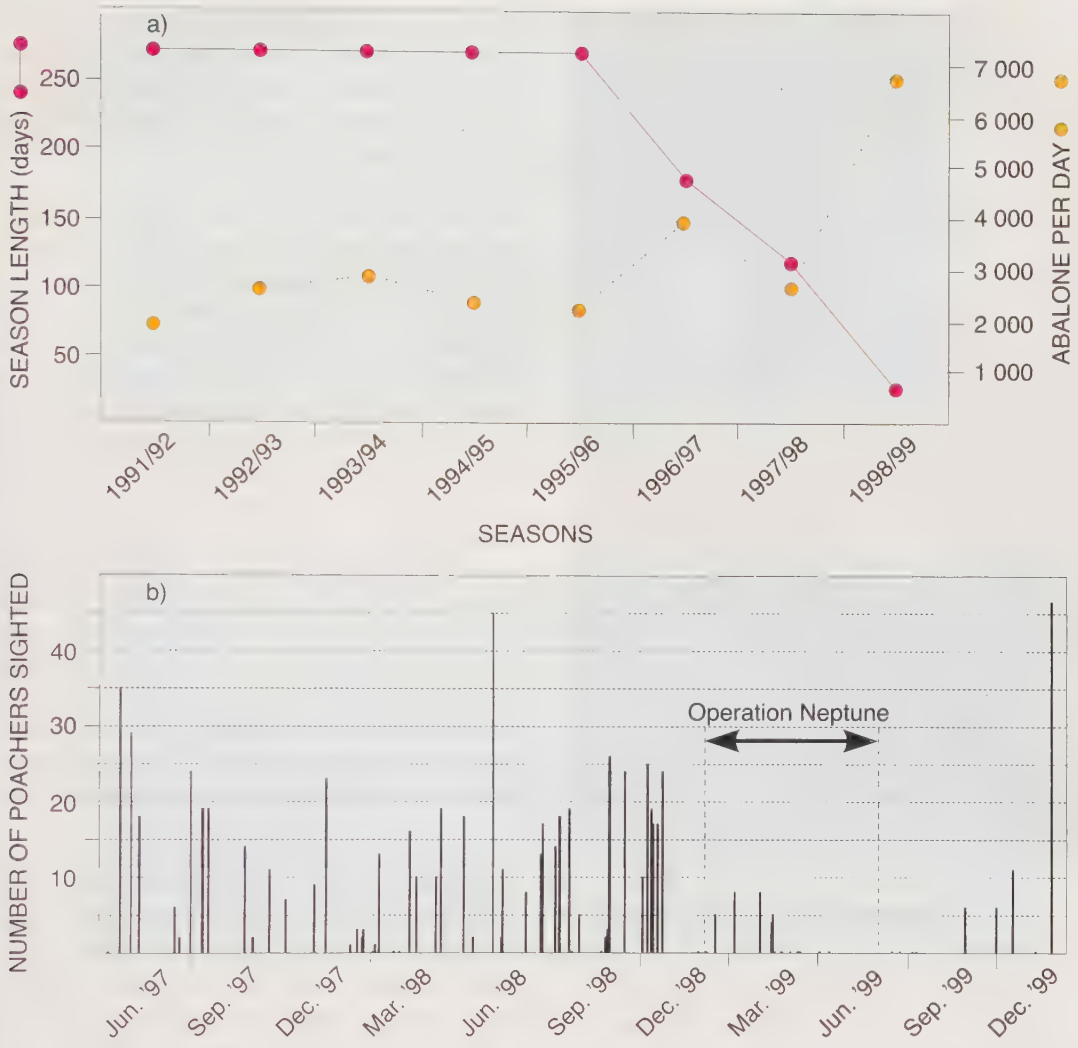

Fig. 14: (a) Length of recreational season and number of abalone landed per day, and (b) aerial sightings of poachers

Unfortunately, owing to funding shortages, Operation Neptune was stopped towards the end of 1999, after which poachers became more visible again.

Seaweed

As part of a long-term study to map the biomass and distribution of kelp on the West Coast, infrared aerial photographs were digitized and the resulting maps geo-referenced. Additional information such as kelp biomass and density can now be incorporated using Geographical Information Systems (GIS). This will ultimately allow the production of detailed maps to aid in the management of harvesting (Fig. 15) and resource allocation.

Experiments continue on the cultivation of *Gracilaria* in St Helena Bay on the West Coast, where a local community group has applied for rights to farm this red seaweed. Current research efforts are aimed at optimizing the mariculture

Fig. 15: A young girl poses with her intertidal harvest of limpets and seaweed, near Port St Johns, along the Transkei coast. Several Gelidium *species are collected informally, and provide income for the poor rural women. A current study indicates that harvesting of these agar-producing species is self-limiting, and along the Transkei coast most of the biomass is in inaccessible areas*

of *Gracilaria* on netting lines suspended from rope "rafts", for agar production or as abalone feed. Growth has been monitored since early 1998 and averages about 4% per day. Predictably, growth is best in spring and lowest in winter, about 6% and 3% per day respectively. The possibility of increasing yields per unit area by using vertical rather than horizontal cultivation lines was investigated. Growth rates were similar at depths between 0.5 and 1.5 m, but then declined sharply with depth so that at 4 m, growth was 40% lower than near the surface, owing to lower light levels. In a commercial *Gracilaria* farm, there may be potential to improve yields by using short (1.5 m) vertical lines, but if they were too closely spaced they would limit light penetration and cause self-shading.

An M&CM seaweed scientist is collaborating with researchers from the University of Cape Town (UCT), the KwaZulu-Natal Nature Conservation Services and the State University of Ghent, Belgium, in a project to document the seaweed biodiversity of KwaZulu-Natal. This project, together with another biodiversity-related project, forms part of a broader initiative to document the seaweed flora of South Africa.

The red seaweed *Porphyra* is a good supplementary diet for farmed abalone, and concerns about its sustainable harvesting led to M&CM funding a UCT-based Ph.D. study of local stocks. The student involved presented the management-related findings at an international EU-funded *Porphyra* workshop in Plymouth, UK, in March 1999, and published three scientific papers on various aspects of the study. Results indicate that local *Porphyra* populations, consisting of several species, are spatially and temporally patchy. Careful harvesting is possible, but it is important that some patches remain intact on any exploited shore to ensure spore production and recovery of biomass. *Porphyra* remains viable for long periods when dried, more than one year if it is stored at –18° C. This seaweed can therefore be collected over a wide area, stored and transported, avoiding over-exploitation on shores close to abalone farms. However, the effects of any commercial collection will have to be monitored over the long term.

Rock lobster

West Coast rock lobster

The West Coast rock lobster *Jasus lalandii* resource remains heavily depleted relative to its estimated pre-exploitation level in the late 1800s. This is a consequence of both the taking of large, unsustainable catches between 1900 and 1960

and a recent considerable reduction in somatic growth rate of individual rock lobsters. As a direct consequence, the global *TAC* was reduced from 2 300 tons for the 1998/1999 fishing season to 2 156 tons for the 1999/2000 season.

The total *TAC* of 2 156 tons comprised a commercial *TAC* of 1 720 tons, a subsistence *TAC* of 145 tons, and a recreational *TAC* of 291 tons. Twenty-five tons from the commercial *TAC* were set aside to be used for an experimental fishery to assess the resource east of Cape Hangklip. Twenty-five one-ton quotas are currently being assigned to experimental right-holders (10 each at Kleinmond and Hermanus, and 5 at Gansbaai) and it is hoped that they will begin fishing during July 2000. An intensive monitoring programme accompanies this experimental fishing. Obtaining data and information from subsistence fishers remains difficult.

Restriction of the recreational catch to 291 tons was controlled by shortening the season and limiting recreational fishing to weekends and public holidays only at the end of January. The season ended on 24 April 2000.

Substantial research, aimed at improving the existing OMP, has been conducted over the past year – with considerable focus on the re-evaluation of the input data. Consequently, the assessment model has been improved considerably and now reflects a substantially better fit to the available data. Although the OMP was due for revision early in 2000, following a workshop between industry and M&CM, it was agreed to continue with the existing (but improved) OMP for use in setting the 2000/2001 *TAC*. A revised management plan would be implemented by June 2001 for the setting of the 2001/2002 *TAC*.

One of the most severe complications affecting rock lobster has been a series of strandings. Red tide-associated walkouts have been increasing in frequency over recent years. Following the major stranding event at Elands Bay during April and May 1997, there were further strandings in the same area during May 1998, 1999 and 2000. The latter was a small event with only about 5 tons being washed ashore. The management plan developed and revised over the past two years for dealing with these events ensured a smooth and coordinated response to the 2000 walkout. Consequently, most of the stranded rock lobsters were collected and returned to the sea away from the area affected by the red tide.

Research into the efficacy of the rock lobster sanctuary areas has continued. To date only four rock lobsters have been observed in the St Helena Bay rock lobster sanctuary – indicating that rock lobster abundance in Zone C has still not recovered from the black tide event that decimated the population in the area in 1994. Whereas trap catches of rock lobsters in the Table Bay rock lobster sanctuary were significantly smaller when compared to adjacent exploited areas (Fig. 16), the abundance and catch of rock lobsters in the Saldanha Bay rock lobster sanctuary and the Betty's Bay marine reserve were comparable with adjacent areas. It was estimated that about 7% of total egg production in 1998 originated from within the reserve and sanctuary areas – about the same as the proportion of the coastline over which rock lobsters are protected.

Patterns of small- and large-scale movements of *J. lalandii* are being investigated in conjunction with the sanctuary study. Analyses on returned tags since 1968 show that only about 0.5% of rock lobsters have moved more than 5 km between the time of release and recapture. Initial results arising from experiments conducted in the Two Oceans Aquarium kelp tank suggested that rock lobsters show strong hole fidelity. When the experiments were repeated in the field, rock lobsters showed affinity to areas of about 10 m × 10 m, rather than fidelity to specific holes. Consequently, it is likely that spillover of rock lobsters from the reserve areas to adjacent fishing zones is limited.

Aquarium and field experiments are underway to examine escapement rates of rock lobsters from traps with different mesh sizes. The overall aim is to reduce the catch of undersize rock

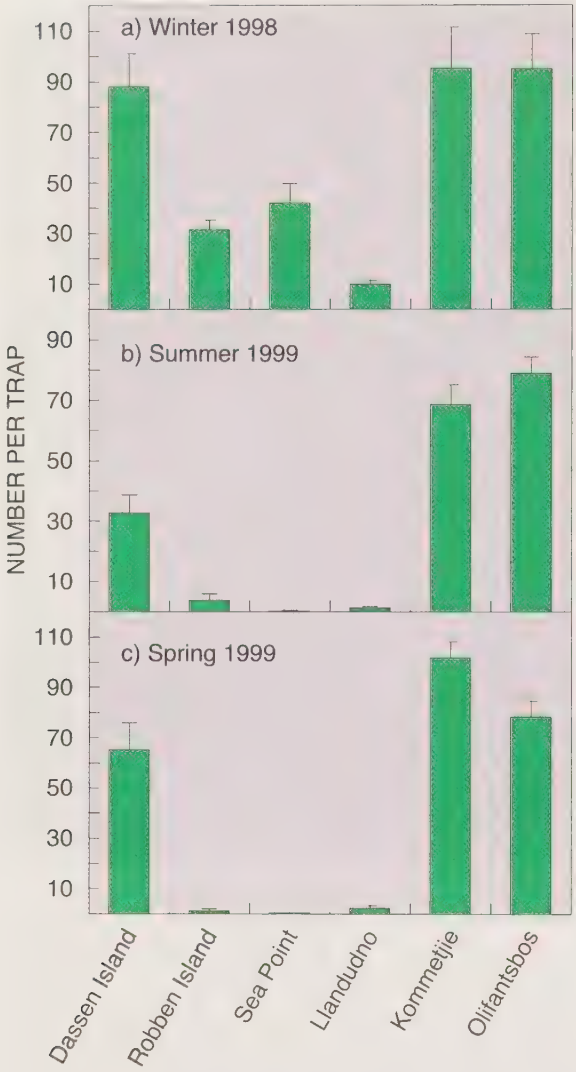

Fig. 16: Catch as number of rock lobster per trap in six fishing areas. Error bars are +1 SD

lobsters while ensuring that few rock lobsters of legal size escape.

Deep-water rock lobsters

Trends based on *cpue*, evaluated for the South Coast rock lobster *Palinurus gilchristi* resource, have indicated a continuous decline in biomass since the 1988/1989 season. To alleviate the fishing pressure on the resource, a phased reduction of the *TAC* was agreed upon in 1994. This process was implemented from the 1994/1995 season onwards, as downward steps of 25 tons (tail mass) per year. As a result, the *TAC* for the 1999/2000 fishing season was set at 377 tons. However, the *TAC* reductions hardly seem to have impacted on the decline in biomass, which now appears to be greater than 50% of that of 1988/1989. It is likely that further reductions, possibly to a level as low as 300 tons per year, will be implemented over the course of the next three years.

The possibility that the decline in *cpue* is (at least in part) a reflection of trap saturation effects arising from the surfeit of traps now in use in the fishery, was investigated during a trap-reduction experiment conducted between December 1998 and May 1999. The experiment aimed to remove trap saturation effects by reducing the numbers of traps on the fishing grounds. Conceptually, trap-saturation effects would occur when traps placed at high densities compete with one another for the available lobsters in an area (i.e. effective areas fished by traps on adjacent lines overlap) and/or when an increase in the numbers of traps in the fishery results in a greater proportion of the total trap compliment being placed in sub-optimal fishing areas because of space limitations in optimal fishing areas (i.e. increased occupancy of the fishing grounds). The results of the experiment were inconclusive, with some area-season treatments showing an increase in *cpue* at reduced effort, but with others showing no increase, or even a decrease in *cpue* at lower effort. These inconclusive results were likely caused by areal and seasonal catchability fluctuations. The effort-reduction experiment was described in more detail in the 1998–1999 edition of *Research Highlights*.

Several new permits for the 1999/2000 fishing season were granted to applicants belonging to previously disadvantaged communities. To accommodate new right-holders within the 377-ton *TAC*, allocations to existing quota-holders were reduced. In an interesting development, a number of new right-holders have combined their allocations, and have invested in a new fishing

vessel, which joined the fishery in May 2000. This addition increases the size of the fishing fleet to 14 active vessels. This increase in capacity in the fishery is controversial, given that the reduced biomass and lower catch rates experienced in the fishery predicate that capacity should rather be reduced.

Biological research of *P. gilchristi* in 1999 and 2000 has focussed on migration patterns and moulting seasons. An extensive tag-recapture time-series (1988–2000; ~3 000 recaptures) has proved invaluable, and analysis of this information has indicated a large-scale eastward migration, with some individuals moving more than 600 km from the western Agulhas Bank to the Port Elizabeth area. The implications of this migration pattern for the management of the resource have not yet been identified.

No trap-fishing for Natal deep-water rock lobster *P. delagoae* was allowed in South African waters in either 1999 or 2000. The trap-fishery for this species in Moçambique also appears to have been curtailed. However, small quantities of *P. delagoae* (< 20 tons per year) are still landed by the trawlers participating in the multispecies crustacean trawl fishery along the east coast of South Africa.

HIGHLIGHTS OF SUPPORTING RESEARCH

Impact of suspended mussel culture on the benthic environment

The environmental impact of raft-culture of the bivalve *Mytilus galloprovincialis* was studied in winter and summer in Saldanha Bay zoned for multiple uses together with aquafarming (Fig. 17). Sediment cores to a depth of 25 cm were analysed for organic carbon, nitrogen and total reduced sulphides (TRS). *In situ* benthic oxygen exchange rates and nutrient fluxes (ammonium and phosphate) were measured using a data-logging respirometer and benthic chambers in 2-h incubations under a raft within a 80-ha farm and at three reference sites. Macrofauna covered by the chambers (0.115 m^2) was extracted for analysis of biomass, taxonomic composition and trophic grouping.

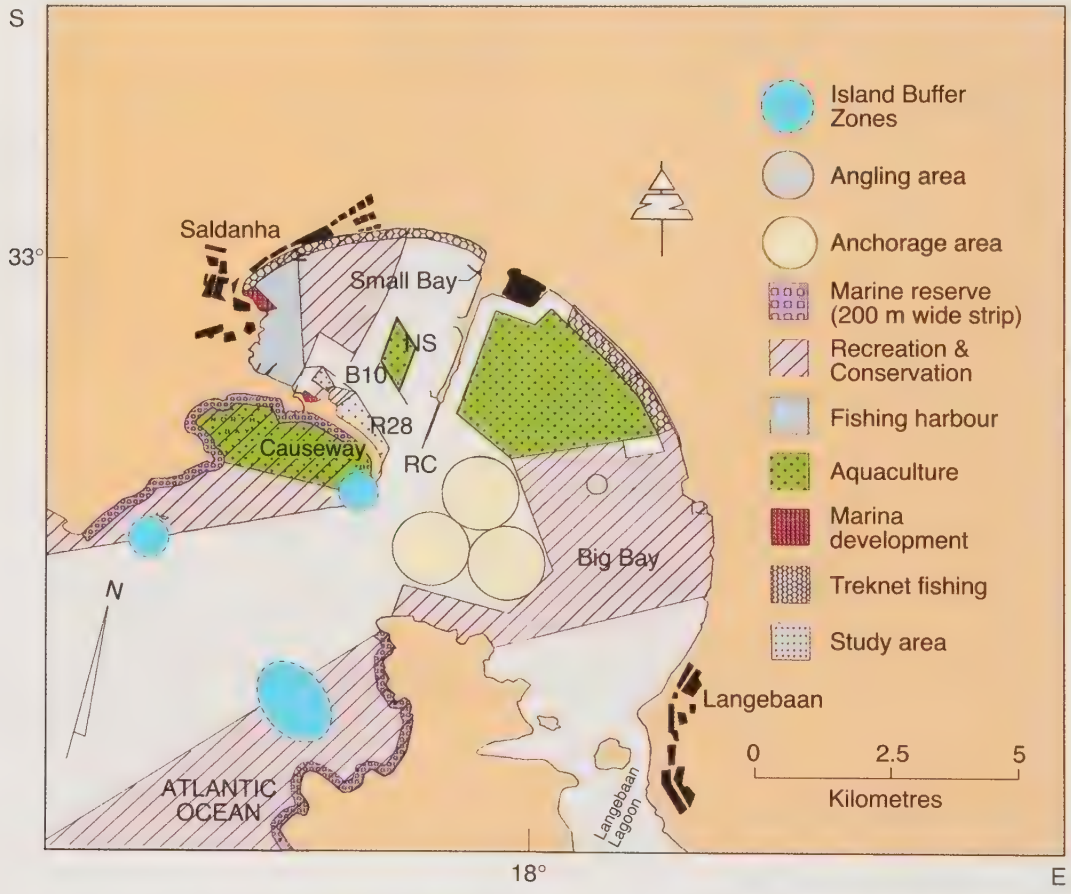

Fig. 17: Saldanha Bay with the position of the present mussel farm (study area with R28 site), reference sites (RC, B10, NS) and two new lease sites, one of 50 ha in Small Bay and the other, 1 000 ha in Big Bay. The bay was zoned for different activities by the Saldanha Bay Environmental Forum in 1997

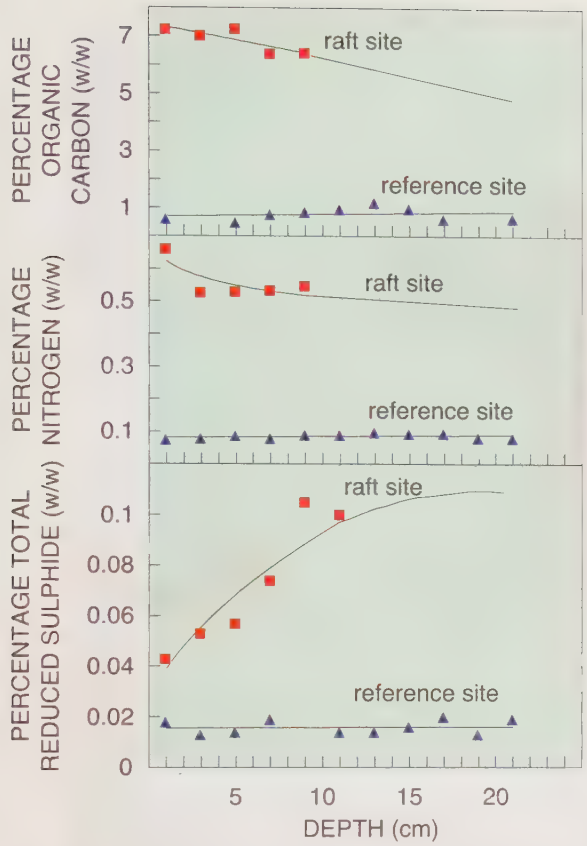

Fig. 18: Vertical sediment core profiles (25 cm deep) at the raft site (R28) and a reference site (RC) showing percentage by weight of organic carbon, nitrogen and total reducible sulphur with fitted trendlines

The organic C content of surface sediments (% by weight) under the raft was an order of magnitude higher relative to the reference site (Fig. 18). Downcore, C content declined below the suspended mussels, but at a 20-cm depth, it was still 5 times that in sediment outside the farm. Percent organic N followed a similar trend in sediments. TRS (%) in surface sediment was only marginally higher beneath the mussels, but downcore to 20 cm the content increased threefold compared to the reference site (Fig. 18). There was no consistent trend in O_2-exchange rates that could separate raft sediments between sites or seasons; measurements ranged between 1 and 2 $\mu mol \cdot m^{-2} \cdot h^{-1}$. Raft ammonium flux was distinctly higher in winter, 1.4 $\mu mol\ NH_4 \cdot m^{-2} \cdot h^{-1}$, which is 4 times that at the reference sites and 2.5 times the raft summer flux. Phosphate fluxes presented no conclusive result, two reference sites being atypical in having the highest rates with wide variation. This shows that more than one reference site in impact studies is desirable.

The ratio of ammonium and phosphate fluxes proved a sensitive index of raft impact, winter ratios being higher than in summer and both being consistently greater at the raft site than at the reference sites (Fig. 19).

Macrofauna biomass was substantially less at the raft site and was dominated by detritivores and carnivores, mainly bivalves, gastropods and polychaetes. At reference sites larger individuals elevated the biomass up to 30 times that under the raft; suspension feeders, mainly anomurans, echiuroids and bivalves, were dominant. Macrofauna biomass alone could not account for the observed oxygen exchange rates and ammonium fluxes. This latter proved the most sensitive measure of raft-culture impact, possibly because it integrates the complexity of interactions between denitrification, ammonification and decomposition on the one hand, and ammonium excretion by fauna and the role of bioturbation in accelerating surface exchange on the other hand. Sedimentary NH_4 flux was extrapolated to the farm scale to account for expansion from 50 ha (3.8 $\mu mole\ NH_4 \cdot m^{-2} \cdot d^{-1}$) to 1 000 ha (7.7 $\mu mole\ NH_4 \cdot m^{-2} \cdot d^{-1}$). This was compared to natural regeneration of NH_4 on the bay scale from new primary production (28.0 $mmole\ NH_4 \cdot m^{-2} \cdot d^{-1}$). It was concluded that the effects of sedimentary NH_4 release would be localized to raft/farm scale and that water quality on a bay scale would be unaffected.

Near-surface current regimes in the Benguela and southern Angola current systems

New information on near-surface currents between Cape Town and Namibe (Angola) was

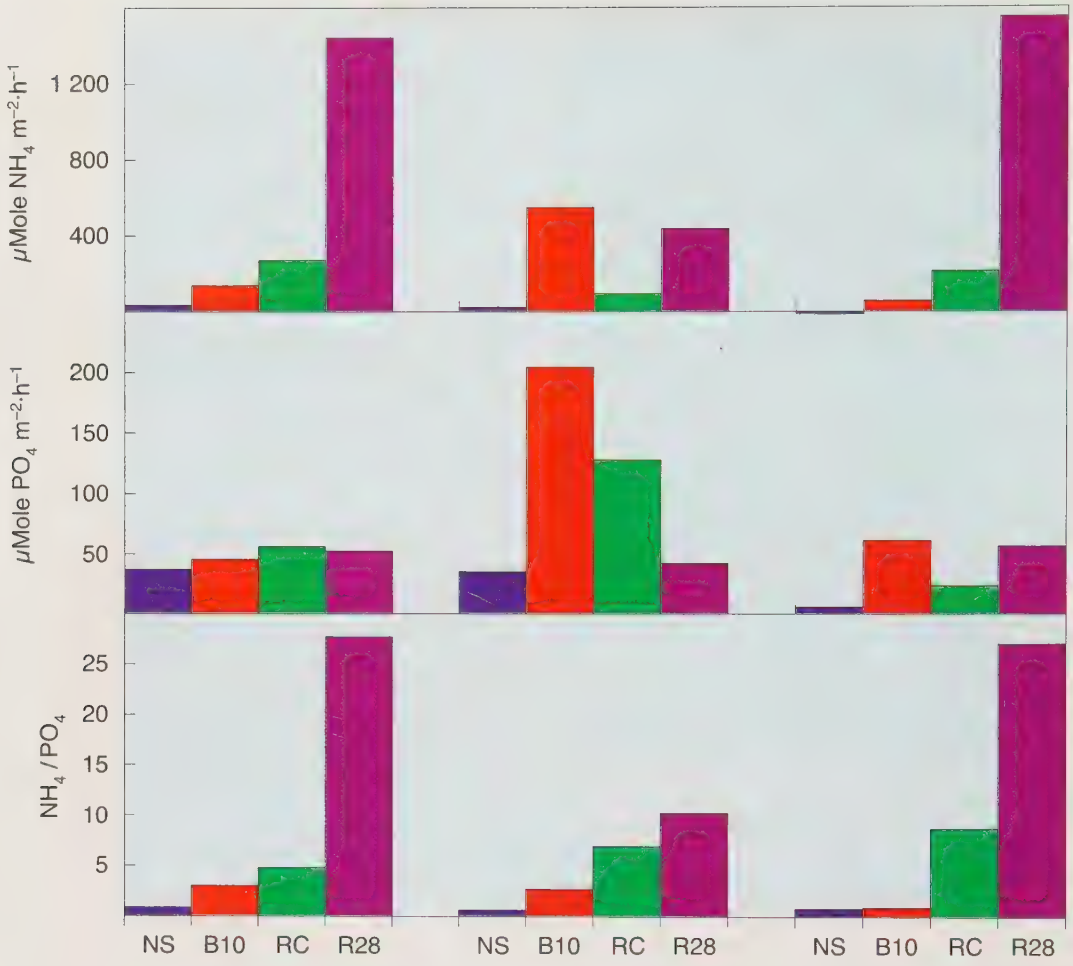

Fig. 19: The ratio of fluxes of ammonium and phosphate in winter (1997) and winter and summer (1998) calculated from the means

collected on the June-July 1999 BENEFIT Research Training Cruise onboard the FRS *Africana* by means of an ADCP and satellite-tracked drogues. This information not only added substantial weight to previous descriptions and hypotheses regarding flow patterns in the region, including results from recent cruises onboard the Norwegian RV *Dr Fridtjof Nansen* (see *Research Highlights 1998–1999*), but also showed new features.

The results obtained are shown schematically in Fig. 20 and can be summarized as follows (numbers below refer to those in Fig. 20). Comparison with previous data shows that the Angola-Benguela Front is located further north in winter than in autumn, but that the general dynamics appear to be similar, with partial onshore flow close to the coast and clear offshore flow coincident with the front (1). Excluding the direct effect of wind on the surface layer, northward flow occurs mainly near or inside the 200-m isobath, with eddies in the mid-shelf region, and southward flow offshore (and sometimes inshore). During the survey in June 1999, no southward undercurrent was at all present on the inner shelf, which is unusual (2). In the upwelling regions

off southern and central Namibia, the waters were cool and the currents were weak, with many small frontal systems being observed (3). Offshore flow with weak average velocities was measured on the Orange River Cone, but further north (in the region south of Lüderitz) onshore flow following the bathymetry was measured using drogues and ADCP. This flow veered off-

Fig. 20: Schematic representation of current regimes in the Benguela Current region and the southern part of the Angola Current system

shore at 26°S (4). A specific site for onshore flow was again indicated south of Hondeklip Bay (5).

Overall, four key characteristics of the currents can be emphasized. First, the fastest currents are associated with the warm, advected water masses, i.e. from the Agulhas Bank in the south and the Angola Current in the north. Second, linkage in northward flow from South Africa to southern Namibia can occur around the Orange River Cone, but then this flow moves offshore off Lüderitz. Third, bathymetry and winds affect the near-surface thermal structure; this drives currents around bathymetric features (e.g. the Orange River Cone) and offshore around upwelling centres (e.g. Lüderitz). At the Angola-Benguela Front the dynamics are different. Fourth, inertial motion is the dominant motion in many areas with weaker residual currents.

With regard to fishing implications, sites favourable for the development and retention of fish eggs and larvae near the coast are clearly identified in all subsystems, with regions of offshore flow (i.e. losses) being fewer particularly in winter. However, the oceanographic mechanisms differ in the various regions, as outlined in Fig. 20.

Phytoplankton ocean colour and pigment absorption properties

Meso-scale observations of phytoplankton chlorophyll using the SeaWiFS ocean colour sensor and detailed pigment measurements were undertaken during the BENEFIT Research Training Cruise onboard FRS *Africana* in the southern Benguela between Cape Town and Walvis Bay in June 1999. Level-1 SeaWiFS data were received on a daily basis during the cruise and processed to Level 2 to yield images of optical parameters and chlorophyll concentration. Pigment samples were collected at sea, and analysed in the laboratory using an advanced High Pressure Liquid Chromatography (HPLC) technique.

The SeaWiFS image in Fig. 21 illustrates the chlorophyll *a* distribution for 25 June 1999 and suggests a two-sector division for the phytoplankton in June 1999. A wide band of pigment extending over a considerable distance offshore between 28.5 and 33°S was observed along the South African coastline, while a narrower band was evident along the Namibian coast from 23 to 28.5°S. A frontal system was prominent between 23 and 25°S at 12–12.5°E, offshore from Walvis Bay, which was confirmed by satellite images of sea surface temperature showing sharp temperature changes from 16 to 19°C across the frontal zone. The image also shows considerable complexity in the pattern of phytoplankton distribution, indicative of the dynamic formation of filaments, eddies and frontal systems in the Benguela Current region.

Accessory pigments are very useful chemotaxonomic biomarkers of the composition of phytoplankton communities. Fucoxanthin (Fuc), peridinin (Per) and zeaxanthin (Zea) are signatures for diatoms, dinoflagellates (Dinoflag) and prokaryotes respectively (Fig. 22). Various nanoflagellates (Nanoflag) are important components of the population and a summation of hexanoyloxyfucoxanthin (H), butanoyloxyfucoxanthin (B), chlorophyll *b* (Cb) and alloxanthin (A) was used to indicate this group. Prokaryotes are tiny cells (<2 μm), nanoflagellates are about 5 μm in size, and diatoms and dinoflagellates are large cells (>10 μm). Data from two contrasting stations off Walvis Bay are shown in Figs 22a and 22b where chlorophyll concentrations at 13.69°E were considerably greater than those at 13.51°E. The pigment signatures indicate that diatoms dominated at the former station with much lower concentrations for the marker pigments of the other phytoplankton groups. At 13.51°E, the accesssory pigments showed that the community was dominated by small nanoflagellates and tiny prokaryotes, with larger diatoms and dinoflagellates being minor components.

The major role of pigments in phytoplankton is to absorb light for photosynthesis, resulting in the growth of phytoplankton cells and increased primary production. The key photosynthetic

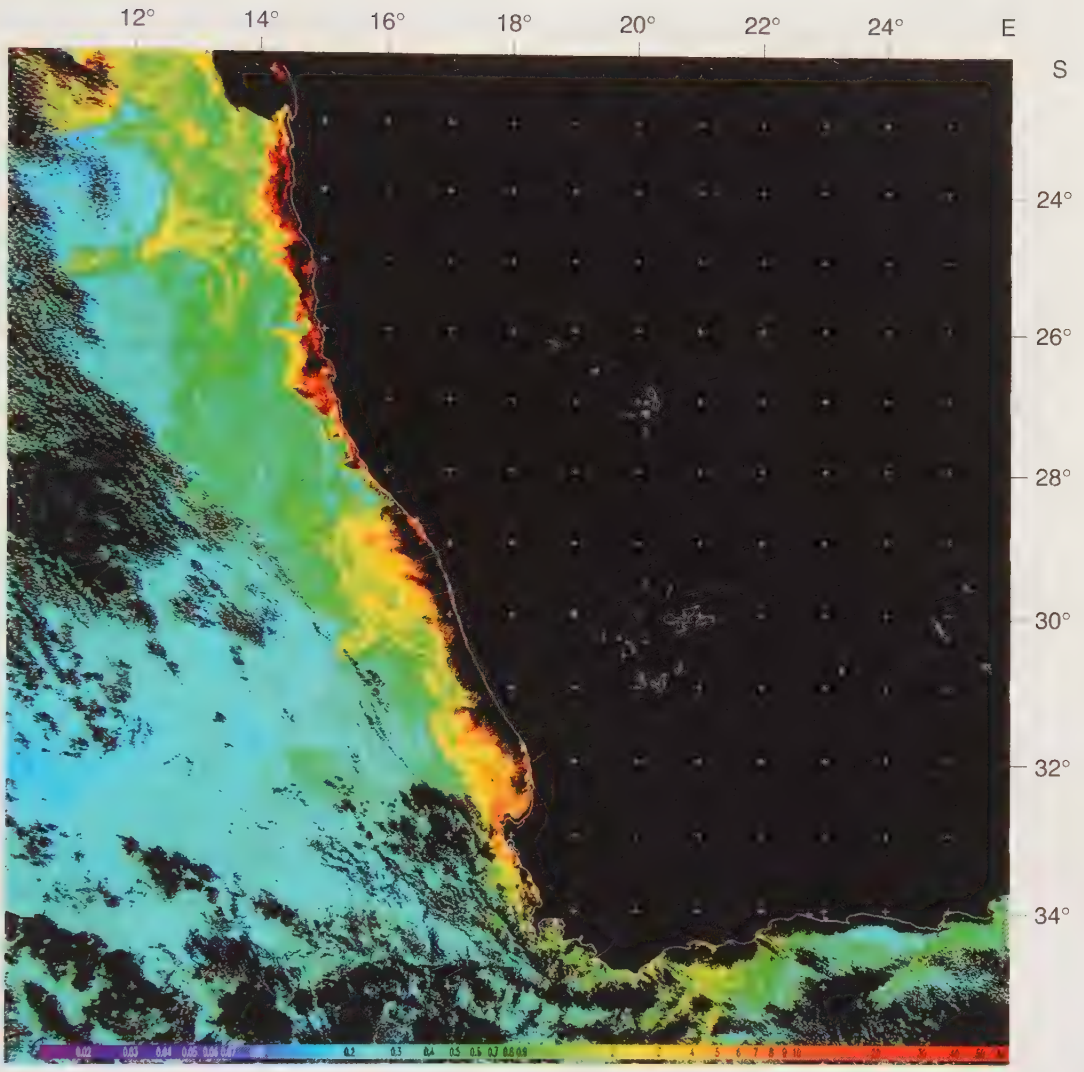

Fig. 21: Chlorophyll a distribution ($mg \cdot m^{-3}$) in the southern Benguela as observed by SeaWiFS on 25 June 1999. The black areas on the image indicate considerable cloud cover and coastal fog patches along the coast that were typical of winter conditions

pigments include chlorophylls *a*, *b*, and *c*, and the photosynthetic carotenoids (PSC) peridinin, fucoxanthin, hexanoyloxyfucoxanthin and butanoyloxyfucoxanthin. In addition, other pigments such as violaxanthin, diadinoxanthin, alloxanthin, zeaxanthin and ß-carotene serve a role as photoprotective carotenoids (PPC) to shield phytoplankton cells from the photoinhibiting effects of high light intensity in the surface layers of the ocean. To assess these bio-optical properties, a reconstruction technique was utilized to estimate the absorption spectra of the phytoplankton community and the proportional contribution of each pigment group. Pigment concentrations and *in vivo*, weight-specific absorption coefficients for chlorophyll *a*, *b*, and *c*, PCSs and PPCs are used in this technique. The proportional contribution by the pigments to the chlorophyll *a*-specific absorption (a^*_{ph}) at 440 and 490 nm, two significant spectral absorption wavelengths, is different

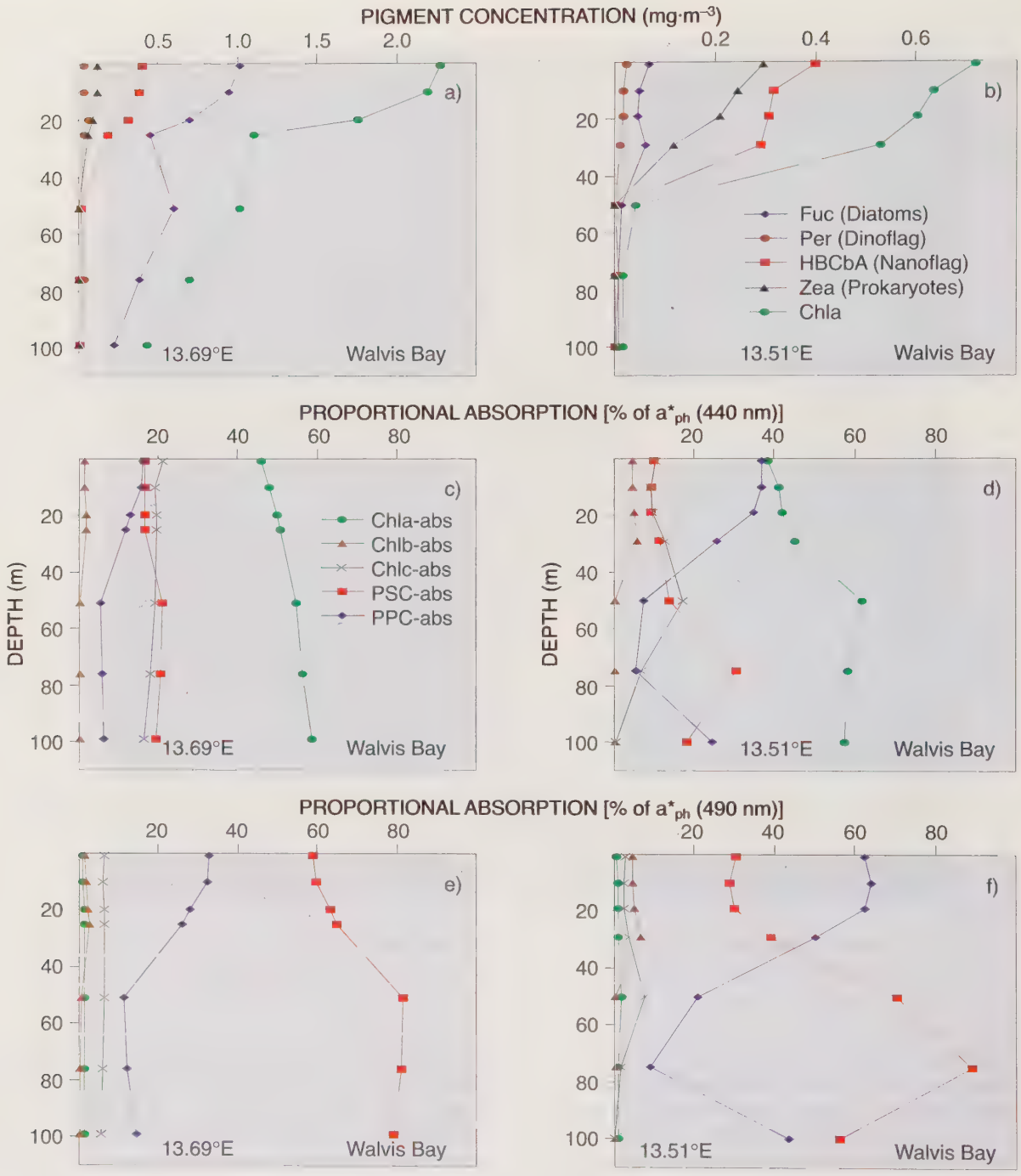

Fig. 22: Depth profiles of pigment concentration (a, b) and proportional absorption at 440 nm (c, d) and 490 nm (e, f) for two contrasting stations on a line off Walvis Bay

(Fig. 22c–f). For the diatom-dominated community at 13.69°E, chlorophylls *a* and *c* and PSC accounted for most of the absorption at 440 nm (Fig. 22c) and PSC at 490 nm (Fig. 22e). At station 13.51°E, chlorophyll *a* and PPC were the major absorbers at 440 nm (Fig. 22d) and PPC at 490 nm (Fig. 22f) in the upper 30 m, but PPC absorption declined between 30 and 100 m as PSC absorption increased.

In summary, the results suggest that diatom-dominated communities have developed an efficient set of light-harvesting pigments to maintain active levels of photosynthesis and high primary production. In contrast, it appears that nanoflagellate-prokaryote communities are susceptible to photoinhibition and have evolved an effective suite of photoprotective pigments to shield the photosynthetic apparatus from high light intensities in surface waters, thereby maintaining photosynthetic activity under stressful conditions.

3-D modelling of pelagic fish recruitment in the Benguela

The development of computer models has dramatically expanded over the last ten years, mainly as a result of the exponential increase in computer performances. Today, computer models of ocean circulation are basic tools used to explore the dynamics of the oceans in three dimensions over a wide range of temporal and spatial scales. Large-scale ocean-atmosphere coupled models are able to reproduce the seasonal dynamics of the ocean over a whole ocean basin. Such models are commonly used to forecast *El Niño*-Southern Oscillation (ENSO) events in the Pacific and their impacts on the world climate. At a much smaller scale, hydrodynamic models are used for coastal management purposes such as estuaries dynamics, harbour development, impact of pollution, etc. The circulation model presented here lies in between those extreme scales. It is a coastal model of the southern Benguela ecosystem covering the continental shelf and the adjacent open ocean, from the Orange River on the West Coast to Port Elizabeth on the South Coast.

Individual-based models (IBM) were developed in the 1980s to describe differences and interactions between individuals within a population. IBM models allow integration and spatialization of environmental, ecological and biological data. With the development of new programming languages such as Java, those models have been very successful in ecology, particularly in the field of marine ecology. Today, they appear to be complementary to classical fish population dynamics models.

After validation of these IBMs, physical and biological models can complement, and sometimes provide an alternative for, experimental research (such as cruises, moorings, biological sampling) in exploring the complexity of hydrological processes, biological processes and their linkage. This is particularly useful as *in situ* research will never be able to provide data at a resolution comparable with the spatial and temporal details provided by a computer model.

The set of computer models presented here is aimed at exploring how physical processes can affect anchovy recruitment success in the Benguela. This is an applied modelling project, which is multi-disciplinary as it brings together physicists, ecologists, biologists and modellers. Under the umbrella of the bilateral VIBES-IDYLE programme between South Africa and France, scientists from M&CM, UCT's Department of Oceanography, the Research Institute for Development (RID), France, the Laboratoire de Physique des Océans (LPO), France, are involved in this project.

A numerical hydrodynamic model known as the Regional Ocean Modelling System (ROMS), developed at Rutgers University and the University of California, Los Angeles, has been adapted to the southern Benguela region. The model is shared among a large community of oceanographers throughout the world and uses the basic equations of fluid motion in a rotating framework to calculate current, temperature, salinity and density fields. The surface boundary conditions are a wind-stress field and thermal

radiation. The model solves the equation for each time step, at each point of the grid. A one-year simulation takes roughly 3.5 days to run on a PC, producing about 2 gigabytes of data.

A pie-shaped spatial grid, which follows the south-western boundary of the African continent from 40 to 28°S and from 10 to 24°E, is used. The resolution ranges from 9 km at the coast up to 16 km offshore. Twenty levels are used to describe the vertical structure of the ocean, with the resolution varying from a few metres over the shelf to approximately 100 m in deep water. The model is forced at the surface with wind stress, heat and salinity fluxes derived from ocean-surface monthly climatology. At the boundaries facing the open ocean, an advanced numerical scheme, forced by seasonal climatology computed from the outputs of the AGAPE basin-scale ocean model, connects the model to the surrounding ocean.

After the spin-up phase (one year of simulation), the model gives a realistic portrayal of the known circulation in the southern Benguela, including upwelling along the West Coast and the Agulhas Current in the southern corner of the model domain (Fig. 23). Meso-scale details, such as Agulhas rings, upwelling fronts, filaments and eddies, are also well simulated. In the vertical dimension, the model is able to reproduce known patterns of circulation, notably offshore flow along the West Coast, convergence near the

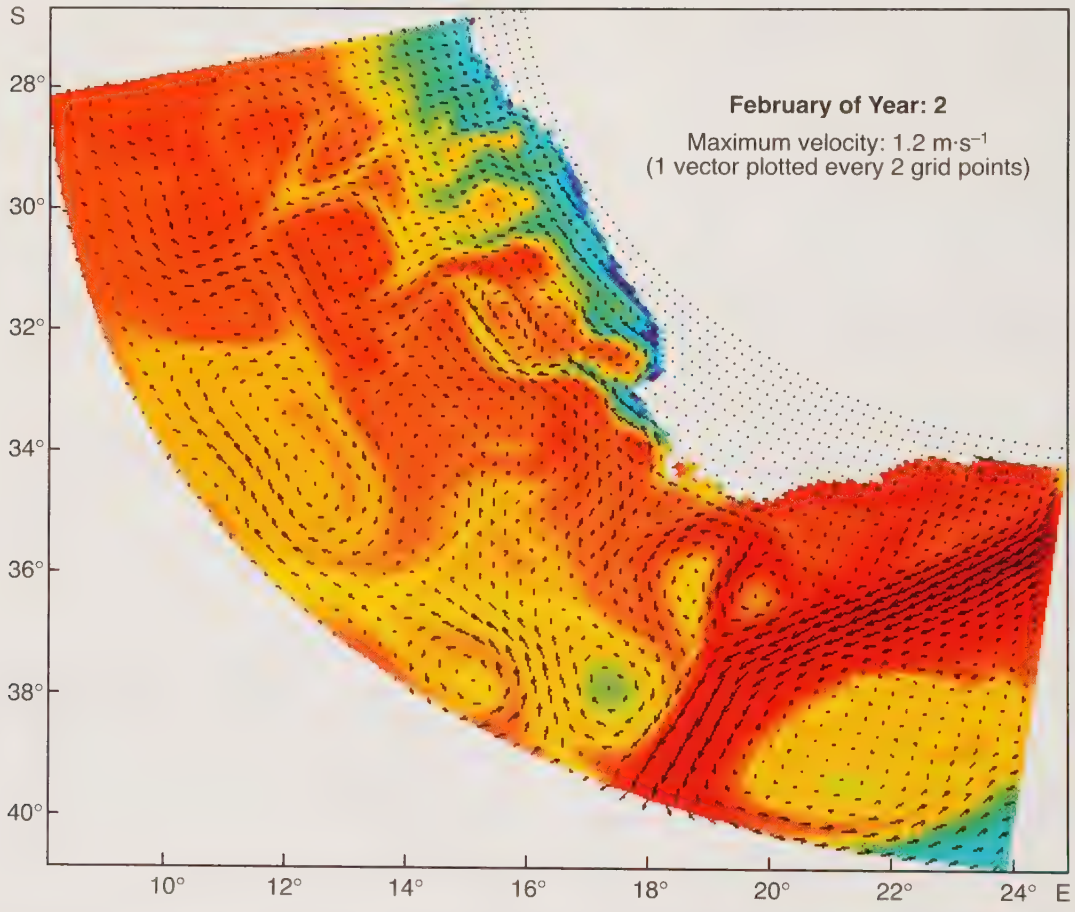

Fig. 23: An example of the output of the model showing the spatial structure of sea surface temperature and of the surface current during the first day of February

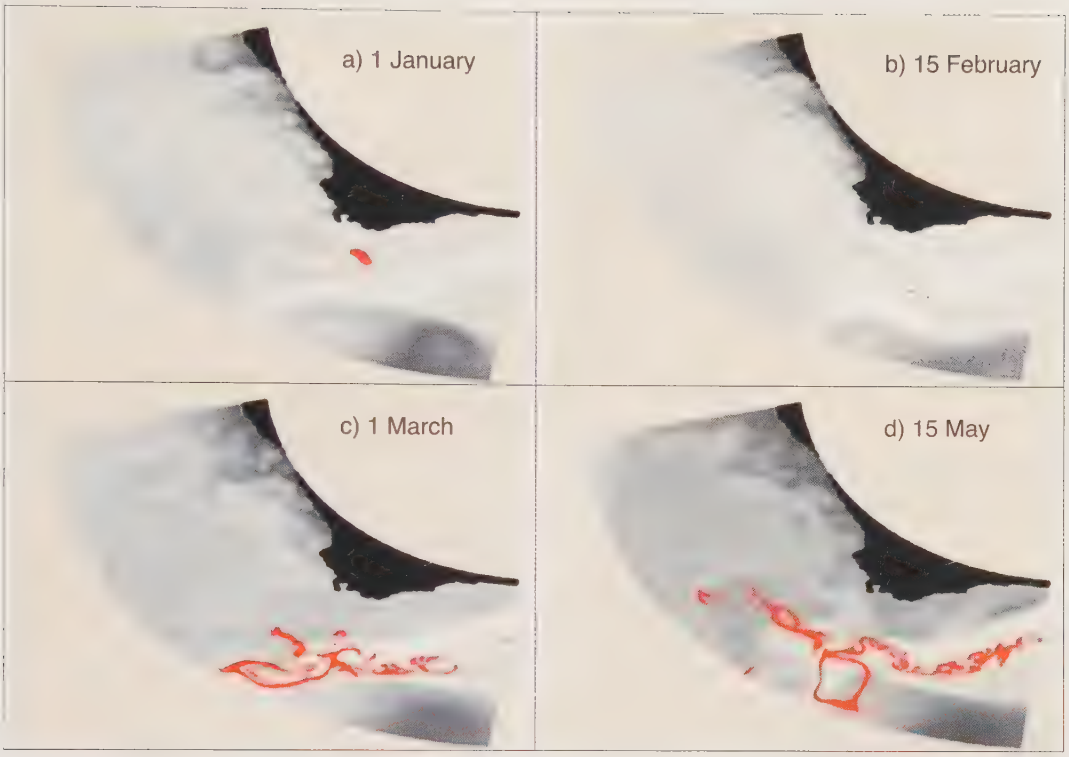

Fig. 24: Results from IBM, showing 25 000 fish-larvae-particles (in red) released near the Agulhas Bank and transported in currents generated by the hydrodynamic model

front and coastal counter-currents. The magnitude of the currents reproduced by the model matches observations made at sea. Comparison between satellite imagery, both sea surface temperature and altimetry, and the output of the model, shows that the size of the meso-scale features matches satellite-derived observations.

In the simulations, numerous anchovy eggs and larvae are distributed in time and space in a virtual physical environment represented by the output of the 3-D hydrodynamic model. Thus, at each time step they are constrained by ecological as well as environmental factors. Survey data of fish eggs, larvae and juveniles collected by M&CM during the last two decades will be incorporated in the simulations as well as biological information such as growth, starvation index, or cannibalism rates, obtained for anchovy in the area. Simulations that reproduce observed distribution patterns as well as patterns that are not observed in nature, are very informative in terms of how and why environmental processes can affect recruitment success. The first developments of the IBM model are presented in Fig. 24.

The IBM will be developed as a generic tool, i.e. to integrate diverse data sources and information relevant to the recruitment problem. It should be used by scientists or anyone interested in other ecosystems where similar scientific questions need to be addressed.

The hydrodynamic model allows a better understanding of the interaction between the circulation over the shelf and topographical features such as Cape Columbine. Our understanding of the interactions between the Agulhas Current and the shelf has also benefited from the analysis of the model simulations. Future developments

will involve a production model that will be used to estimate the biological productivity (phytoplankton and zooplankton) over the coastal domain. First experiments of IBM simulations have shown the complex geometry of the paths of particles in the hydrodynamic flows of the Benguela system. They support Bakun's proposed triad of diffusion, concentration and retention, three mechanisms important in the transport of fish eggs and larvae and their survival, which ultimately determines pelagic fisheries success.

Acoustic identification of anchovy, sardine and round herring schools

Biomass of pelagic fish stocks is currently assessed using hydro-acoustic surveys. The acoustic measurements of back-scattered echo-energy are partitioned among species on the basis of analysis of species composition in midwater trawl samples. This system of species allocation may be biased however, by differences between species in terms of their catchability and by the lower spatial and temporal resolution of trawls in comparison to acoustic techniques. This study tested the hypothesis that anchovy, sardine, and round herring schools can be identified to species level directly from the acoustic data, based on inter-specific differences in school shape, density structure, and position in the water column.

Measurements of school features were extracted from acoustic data records of Spawner Biomass surveys conducted by M&CM in November of 1997 to 1999, using the schools module of the SonarData Echoview software package (developed in collaboration between M&CM and SonarData Inc.). Only schools composed primarily of one single species, as determined by trawl sampling, were examined.

Discriminant function analysis indicated that schools could be correctly classified to species level in 88.3% of the cases (94.9% accurate for anchovy, 82.6% for sardine, and 82.6% for round herring). Sardine were distinguished from anchovy and round herring primarily on the basis of school depth and acoustic energy (i.e. density), and round herring from the two other species based on an index of altitude. Incorporating ancillary information (latitude, longitude, sea surface temperature, bottom depth, and time of day) in the analysis improved the accuracy of school identification to 94.9% (Fig. 25), probably as these variables allowed discrimination on the basis of interspecific differences in habitat use, in addition to differences in schooling behaviour.

The ability to identify species acoustically, when employed in conjunction with trawling, should not only improve the accuracy of allocating back-scattered energy among species, but also enhance stock biomass estimates. Moreover, greater ability of fishers to identify schools acoustically may result in reduced by-catch. Future research will examine the interannual applicability of these findings, determine their impact on survey accuracy, and seek to expand the present analyses

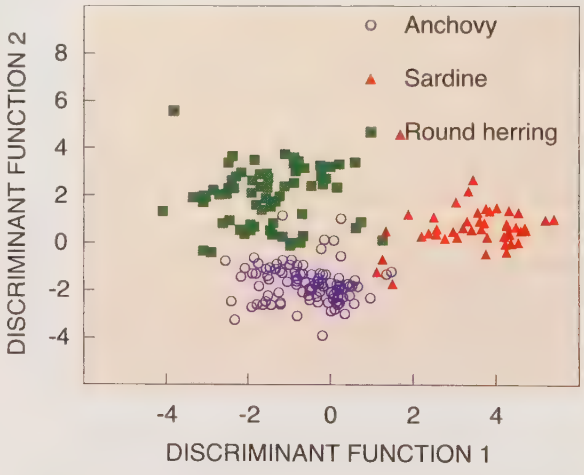

Fig. 25: Discriminant function scores for each school of each species, indicating substantial separation among species in school features. Function 1 is correlated with school mean acoustic energy, depth, altitude index, longitude, and temperature, features allowing discrimination between sardine and the two other species. Function 2 was most highly correlated with the altitude index, bottom depth, and latitude, and primarily discriminated anchovy from sardine and round herring

to include mixed-species in addition to mono-specific schools.

Paralytic shellfish poisoning in abalone *Haliotis midae* on the West Coast

The abalone *Haliotis midae* forms one of the oldest fisheries on the South African coast, with present-day operations including recreational, subsistence and commercial activities. During the 1990s land-based farming of this species has also been under development and has recently attained commercial-scale production. In April 1999 monitoring at two West Coast abalone farms provided evidence of the presence of Paralytic Shellfish Poisoning (PSP) toxins in cultured abalone. On one of the farms several animals were paralysed, in that they were no longer able to attach to a substrate, and some mortalities were also recorded. At this time divers reported the presence of a large number of detached or paralysed abalone in the kelp beds in the vicinity of Paternoster. Analysis of these wild animals also indicated the presence of PSP toxins. Although toxin concentrations varied considerably at each locality, a north-south gradient in toxicity was evident. The single highest toxicity value of 1 609 µg toxin·100 g^{-1} tissue, as measured by the mouse bioassay, was recorded on the northernmost farm. Abalone south of Cape Town did not exceed the regulatory limit for the harvesting of shellfish of 80 µg toxin·100 g^{-1}.

The accumulation of PSP toxins usually occurs when toxic dinoflagellates are filtered from the water by bivalves, which then accumulate the algal toxins to levels that are potentially lethal to humans or other consumers. Considerable progress has been made in the structural elucidation of PSP toxins. Following identification of the parent compound saxitoxin (STX), approximately two dozen naturally occurring derivatives have been described, which vary greatly in their potency and are subject to inter-conversions and changes in relative proportions as they are transferred through the foodchain. PSP off the west coast of South Africa has always been

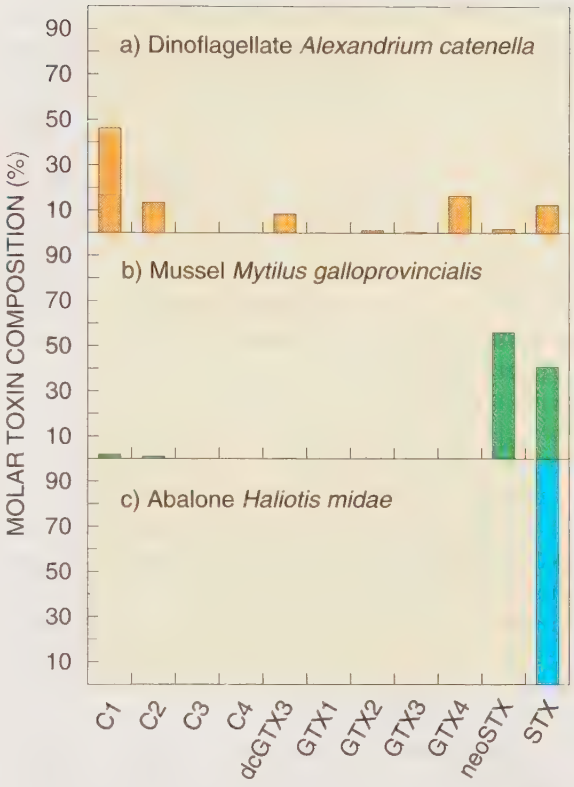

Fig. 26: Toxin composition of (a) a phytoplankton sample with a high proportion of cells of Alexandrium catenella, *(b) the bivalve* Mytilus galloprovincialis *and (c) cultured and wild abalone* Haliotis midae

attributed to the dinoflagellate *Alexandrium catenella*. Abalone, however, typically feed on kelp and other seaweeds making them unlikely candidates for the accumulation of PSP toxins derived from toxic dinoflagellates. Initial observations nevertheless found PSP toxins in abalone to be coincident with blooms of *A. catenella*, indicating that this dinoflagellate was the probable cause of abalone toxicity.

As the mouse bioassay is a non-specific test, analysis by means of HLPC and mass spectrometry was required to identify and confirm the presence of PSP toxins in abalone. At the same time the toxin composition of the PSP-producing dinoflagellate *A. catenella* and the mussel *Mytilus*

galloprovincialis was determined for comparative purposes. This work was undertaken in collaboration with the Instituto de Investigaciones Marinas in Spain.

The relative proportion of various PSP derivatives is a conservative property for any dinoflagellate isolate and the toxin composition of blooms of *A. catenella* on the West Coast was found to be characterized by a high proportion of the less toxic N-sulfocarbamoyl toxins (C_1 and C_2) and moderate proportions of the more potent carbamate (STX and GTX_4) and decarbamoyl toxins ($dcGTX_3$) (Fig. 26a). Analysis of the mussel *Mytilus galloprovincialis* revealed a significant difference between the toxin profile of the causative dinoflagellate and the contaminated bivalve thereby indicating a high degree of toxin transformation (Fig. 26b). It is well known that the toxin composition in bivalve tissues can differ significantly from that of the toxic dinoflagellates ingested and as is often the case with bivalves, the mussels were found to contain reduced proportions of N-sulfocarbamoyl toxins (C_1 and C_2) and higher proportions of the carbamate toxins (neoSTX and STX). This observation is common when the algae ingested are rich in N-sulfocarbamoyl toxins which are more labile than other toxins and therefore more likely to be transformed to their more toxic carbamate analogues. Although the precise *in vivo* mechanism of conversion between N-sulfocarbamoyl and carbamate toxins in shellfish has not been determined it may lead to an increase in net toxicity. The toxin composition of abalone was rather unusual in that it was dominated by a single toxin, notably STX (Fig. 26c). The dramatically different toxin profile of *H. midae* compared to *A. catenella* indicates either a very high capacity for transformation of PSP toxins by abalone or that *A. catenella* was not the source of the toxin.

Investigations indicated that within the abalone fishery recruitment may be severely influenced by PSP. The contamination of abalone with high levels of PSP toxins was accompanied by clinical signs of paralysis in certain animals, including brood stock. Histological examination of affected animals showed no significant abnormalities. Brood stock that recovered resumed spawning, but viable larvae were not produced. Collaborative studies with Onderstepoort Veterinary Institute showed irregular division of eggs and the formation of grossly abnormal larvae (Fig. 27). The larvae were characterized by irregular

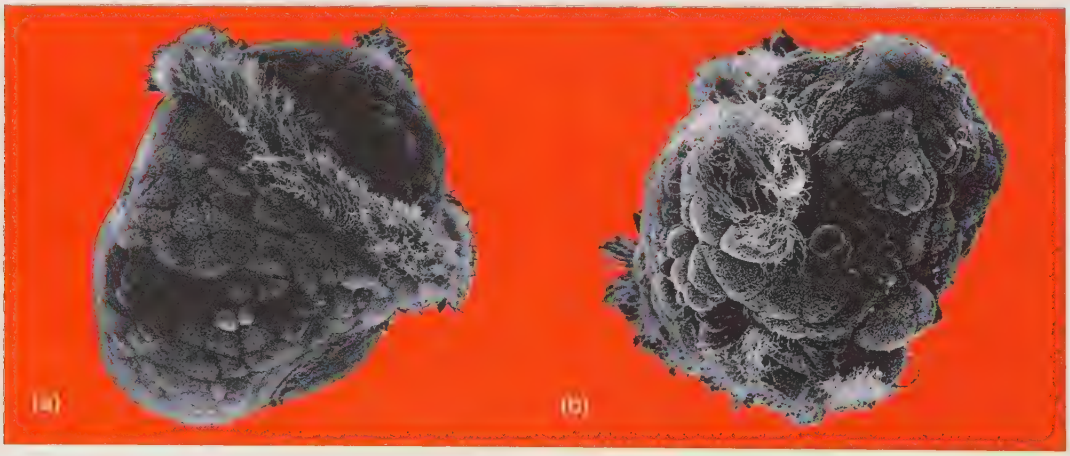

Fig. 27: (a) A normal newly-hatched larva known as a trochophore stage and (b) an abalone larva produced by PSP-contaminated brood-stock. The normal larva is able to swim and remains planktonic for approximately 5 days. It is regular in shape, possesses a clearly defined protostomal tuft and a continuous and complete velum

shapes and the appearance of cilia in clumps over their entire surface. Although most eggs containing such larvae hatched, the larvae were unable to swim and did not develop further. Problems with larval development persisted for several months. It is not possible to say whether the larval abnormalities were directly related to PSP contamination. It is likely that the reproductive problems were caused by the deterioration in brood stock health and that the effect of the toxin on larval development is therefore only indirect. Similar larval abnormalities could probably be caused by other brood stock stressors, but further research is needed to investigate this possibility.

The findings of this study support the need for the inclusion of non-filter-feeding molluscs in routine monitoring programmes. The presence of PSP toxins in abalone now threatens the future of the abalone fishery and the newly-developed aquaculture operations on the west coast of South Africa. This threat is made more ominous by the slow depuration of toxins to below the regulatory level and by our limited understanding of the causes of the problem. Priority areas of research should therefore focus on confirmation of the origin and establishment of the mode of uptake of the toxins.

Winter zooplankton in the Angola-Benguela Front region

The environment at the northern limit of the Benguela Current is governed by the Angola-Benguela Front. At the convergence of the Angola and Benguela currents, this seasonally highly variable hydrographic feature separates two ecosystems, which basically differ in terms of water temperature, salinity, and nutrient concentration, but also in terms of productivity and species composition. Differences in faunal composition are, for instance, well reflected in the fisheries of the region. Whereas artesanal fisheries of a large variety of species prevail off Angola, industrial fisheries of pelagic and benthopelagic resources are more prominent off Namibia. However, comparatively little is known about the spatial variability of the lower trophic levels, e.g. zooplankton, which forms the food source of most fish during at least some part of their life cycle.

Analysis of zooplankton samples collected on board the Namibian RV *Welwitchia* between Walvis Bay and Luanda in July 1999, as part of the BENEFIT Shipboard Research Training Programme in the SADC Region, revealed some interesting patterns. Indeed, distinct differences existed in the abundance, distribution and taxonomic composition of the zooplankton, which were associated with different water masses encountered along the cruise track (Fig. 28a). Stations within the frontal region were characterized by high abundances of total zooplankton (mean = 90.0×10^3 ind·m^{-2}) compared to the Angola Current water to the north (mean = 39.7×10^3 ind·m^{-2}) and the Benguela Current water to the south (mean = 31.2×10^3 ind·m^{-2}).

Throughout the survey area cyclopoid and calanoid copepods were the most abundant, comprising 62% (Angola Current), 64% (front) and 58% (Benguela Current) of the total zooplankton (Fig. 28b). Cyclopoid copepods were more important in the Angola Current region (14%) than elsewhere (5–6%). Gelatinous zooplankters were more abundant in the Benguela Current off Namibia (19%) than in the Angola Current region (5%), and represented only 2% of the total zooplankton within the front. Euphausiids made up 26% of the zooplankton in the latter region, whilst only 14% to the north of it and 12% to the south. Chaetognaths were generally low in abundance, making up only 3–8% of total zooplankton in the area surveyed. Other taxa, which included cladocerans, polychaetes and some other less important groups, represented 5–11% of total zooplankton abundance in the respective regions.

This study, although based on a low-level taxonomic analysis, illustrates the distinct association of zooplankton communities with the hydrography of the Angola and Benguela currents. In particular, it highlights the importance of frontal systems in

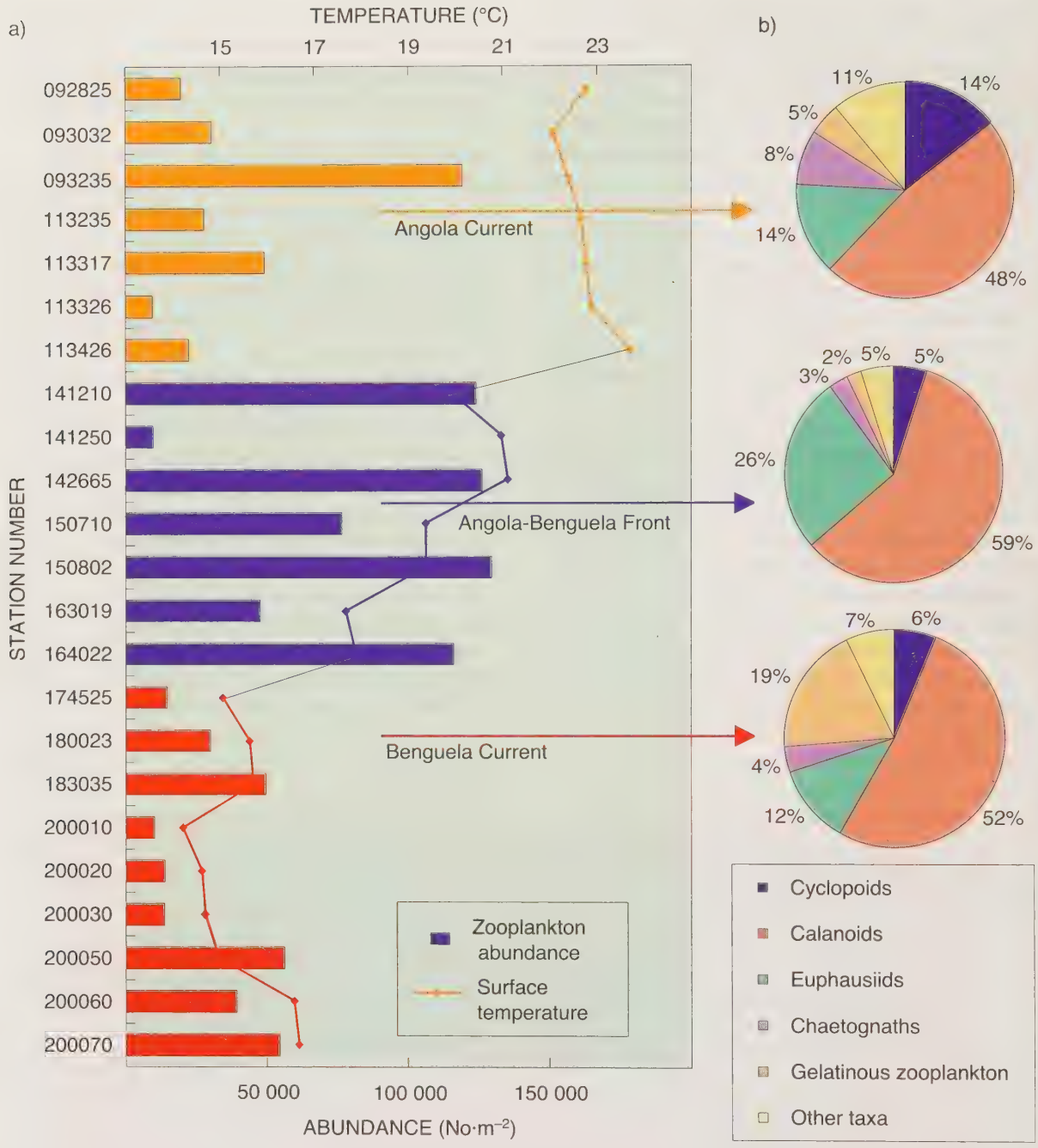

Fig. 28: Longshore distribution of sea surface temperature (°C) superimposed on depth-integrated zooplankton abundance (No·m⁻³) in the upper 200 m between 20°S (north of Walvis Bay) and 09°30'S (Luanda), showing three distinct water masses encountered during the cruise. Also shown is the mean taxonomic composition (%) of zooplankton in the samples pooled for each water mass. Note that the first four digits of the station numbers refer to latitudinal station positions (XX°YY'S), whereas the last two indicate the distance from the shore (in n.miles)

supporting increased zooplankton populations. This suggests that such convergence zones are sites of either physical accumulation of planktonic organisms, or enhanced productivity, or both. More rigorous analyses of the zooplankton at a higher taxonomic level, as well as of the ichthyoplankton component, are underway and will provide more clarity on this hypothesis.

A two-layer oxygen model for the Elands Bay–St Helena Bay area

A two-layer numerical budget model was constructed in an attempt better to understand the low-oxygen water which arrives in the Elands Bay–St Helena Bay area towards autumn. This is often associated with lobster walkouts and beaching of fish. The model applies to a fairly regular part of the shelf between 150 and 200 m sounding over two degrees of latitude from Port Nolloth to the Olifants River mouth. In this region, it is possible to fit a trapezoidal box, allowing for the depth increment moving offshore, with open ends north and south and closed lateral boundaries which inhibit the flux of oxygen. At the top, there is gas exchange with the atmosphere, a process depending on wind speed. This is a now well-researched topic for which an accurate value of oxygenation is available when details of the wind are known. The upper and lower layers are separated by a seasonal thermocline, which inhibits the turbulent transfer of oxygen to the lower layer in summer but breaks down in winter, permitting mixing throughout the water column. This is modelled sinusoidally, with the strongest thermocline occurring in March and the weakest in August.

Deeper water of fixed oxygen concentration enters the box at the north end with the now well-established poleward under-current, at a rate of 5 km per day. There are two sinks for the oxygen budget in this layer, viz. bacterial consumption within the layer and consumption in the benthic boundary layer. An upper layer of 50 m was chosen, leaving an average thickness of the lower layer of 125 m. As the water approaches the shoaling area south of the Olifants River, the bottom layer becomes thinner and spreads out towards the coast.

The model shows a sensitive response to wind. A time-series of wind from the Cape Columbine lighthouse during the period 1979–1991 includes years in which there were weaker winds, notably the mid-1980s (Fig. 29). During these years, the oxygen concentration dropped in the lower layer. The thermocline is seen to have a strong effect on the lower layer, and the sinusoidal seasonal signal is apparent, even for a weak thermocline. Thus, low-oxygen water can be expected in autumn, irrespective of the supply at the northern

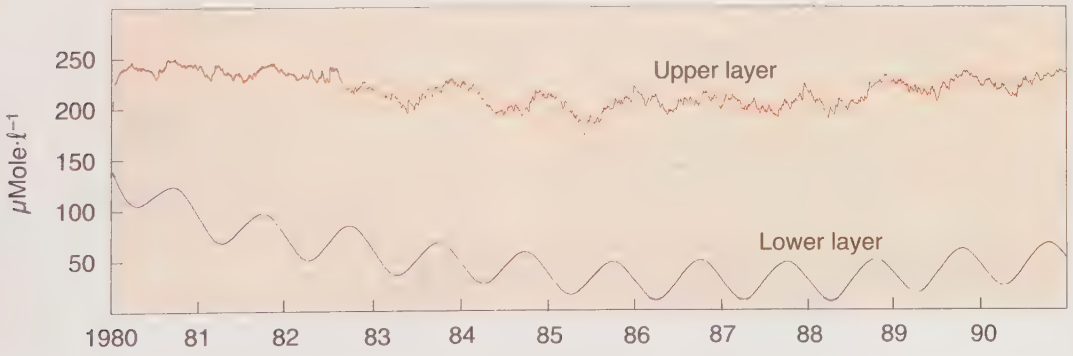

Fig. 29: Time-series of oxygen concentation in the two layers, 1979–1991. Note the seasonal variation in the lower layer, caused by the formation of a summer thermocline, and the secular decrease in both layers, caused by the decline in wind speed in the mid-1980s

end. This raises questions about the continuity of the Angolan low-oxygen intrusion into Namibia. Measurements tend to indicate that low-oxygen water does not spread beyond Lüderitz.

By varying the consumption of oxygen in the lower layer, the benthic boundary layer can be seen to be anaerobic at times of a strong thermocline. The model is generally not very sensitive to realistic variations in lower-level consumption. Episodic events such as sulphurous eruptions over a large area will in reality have an important effect on oxygen levels.

Primary productivity of the shelf region off the west coast of southern Africa in winter

The shelf region of the west coast of southern Africa forms a nursery ground for pelagic fish. During winter anchovy juveniles and recruits move southwards, recruiting to the fishery. The productivity of the West Coast is therefore of interest since the food environment (zooplankton and micro-zooplankton) will affect recruitment strength and fish condition. Few measurements of primary productivity have been recorded in either the southern or the northern Benguela in winter. It is generally considered that productivity would then be at an annual low in the southern Benguela, because of relatively weak insolation coupled with strong mixing of the water column. In the northern Benguela, where upwelling reaches a maximum in late winter-spring, higher rates of productivity are expected.

Primary productivity within the euphotic zone was measured daily on the BENEFIT Research Training Cruises onboard the FRS *Africana* between Cape Columbine and southern Angola, in June-July 1999, using the traditional radiocarbon technique. Measurements were obtained in three oceanographic regimes, the Benguela upwelling region, the Angola-Benguela frontal zone and tropical Angolan waters.

In the southern Benguela, upwelling was very reduced or absent. Nevertheless, water column production rates ranged from 120 to 325 $mgC \cdot m^{-2} \cdot h^{-1}$ and the highest productivity was measured on the Orange River Banks (Fig. 30). In the northern Benguela upwelling was evident off Lüderitz and Cape Frio. In newly upwelled water close inshore, chlorophyll levels and production rates were low. Further offshore, chlorophyll concentrations and production rates attained maxima in maturing upwelled water, and declined in aged upwelled water where nutrients had been depleted in the upper mixed layer. Production rates ranged from 15 to 255 $mgC \cdot m^{-2} \cdot h^{-1}$. The

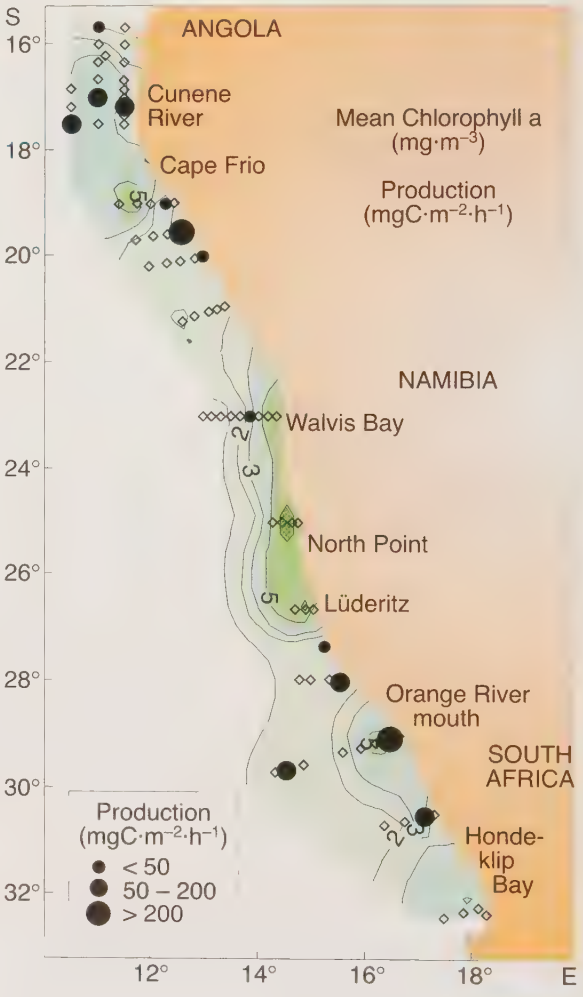

Fig. 30: The distribution of mean chlorophyll (within the upper 30 m) and primary productivity along the west coast of southern Africa in June/July 1999.

highest productivity in the northern Benguela was found off North Point, downstream of the Lüderitz upwelling centre, and off Cape Frio.

The Angola-Benguela frontal zone can be seen clearly in ocean colour images as a massive feature of enhanced chlorophyll concentrations. Productivity measurements within this region were moderately high and ranged from 80 to 175 $mgC \cdot m^{-2} \cdot h^{-1}$. North of the front, in warm nutrient-impoverished tropical Angolan waters, chlorophyll biomass was low, as was primary productivity (<50 $mgC \cdot m^{-2} \cdot h^{-1}$) and the phytoplankton was dominated by nanoplankton (<10 μm in diameter) (Fig. 30).

The daily productivity rates of between 0.1 and 3.5 $gC \cdot m^{-2}$ measured during the BENEFIT cruises are comparable to those obtained in summer off the Cape Peninsula. The wide shelf off the Orange River appears to be a particularly productive and stable area where temporal and spatial variability associated with upwelling is tempered and currents are slow and diffusive in nature.

Are surveys really necessary to manage our resources? The example of the SA pelagic fishery

It has been widely recognized that multiple acoustic surveys conducted by M&CM personnel form the basis for understanding the life history of anchovy and sardine. Such knowledge is essential for implementing a successful management programme. However, with the present reality of budgetary cuts, is it really necessary to continue such an intensive monitoring programme? Could a much simpler system perhaps not deliver the same product to the country, at a fraction of the cost?

Current management of anchovy and sardine is based on an OMP selected on the basis of its ability to ensure the sustainable utilization of both resources. The performance criteria used to select the OMP include the average annual catch over a 20-year projection period, the interannual *TAC* variability, the mean spawner biomass at the end of the 20-year projection period and the risk of collapsing the stock. This risk is defined as the probability of the resources falling, within the projection period, below 20% of mean unexploited biomass. This OMP requires knowledge of a number of biological parameters, such as the size of the stocks, the age structure and mass-at-age of the populations and the natural and fishing mortality-at-age. Many of these can only be estimated accurately from data collected during fishery-independent surveys. The use of imprecise, inaccurate or incomplete data would require a more conservative approach, at the expense of maximizing the use of the resources.

To estimate the economic benefits of the surveys programme for the Industry, the projected average catch of each species over 20 years was computed using the current OMP. The results are plotted against the level of risk under which the resources would be managed (Fig. 31). For the purpose of this exercise, the risk is set at 30% for anchovy and 10% for sardine, which are considered to be acceptable levels.

The results indicate that, under a risk level of 30%, an average *TAC* of 230 000 tons of anchovy can be expected based on both the winter and the summer surveys (Fig. 31a). Cancellation of both surveys would reduce the average catch to 168 000 tons, because the management procedure would have to compensate for the uncertainty associated with the lack of commercially-independent information on the state of the resource. Such reduction would result in an average annual loss (mid-1999 values) to the Industry of approximately R37 million (wholesale value). Should the strategy be to limit the survey programme to one survey per year in summer, the loss of income annually would be approximately R12 million. These estimates would increase at least by 10% if we were to include the sardine by-catch with the anchovy fishery.

Computation of the projected figures for directed sardine catches is not as simple, because the sardine *TAC* is intimately linked to the anchovy

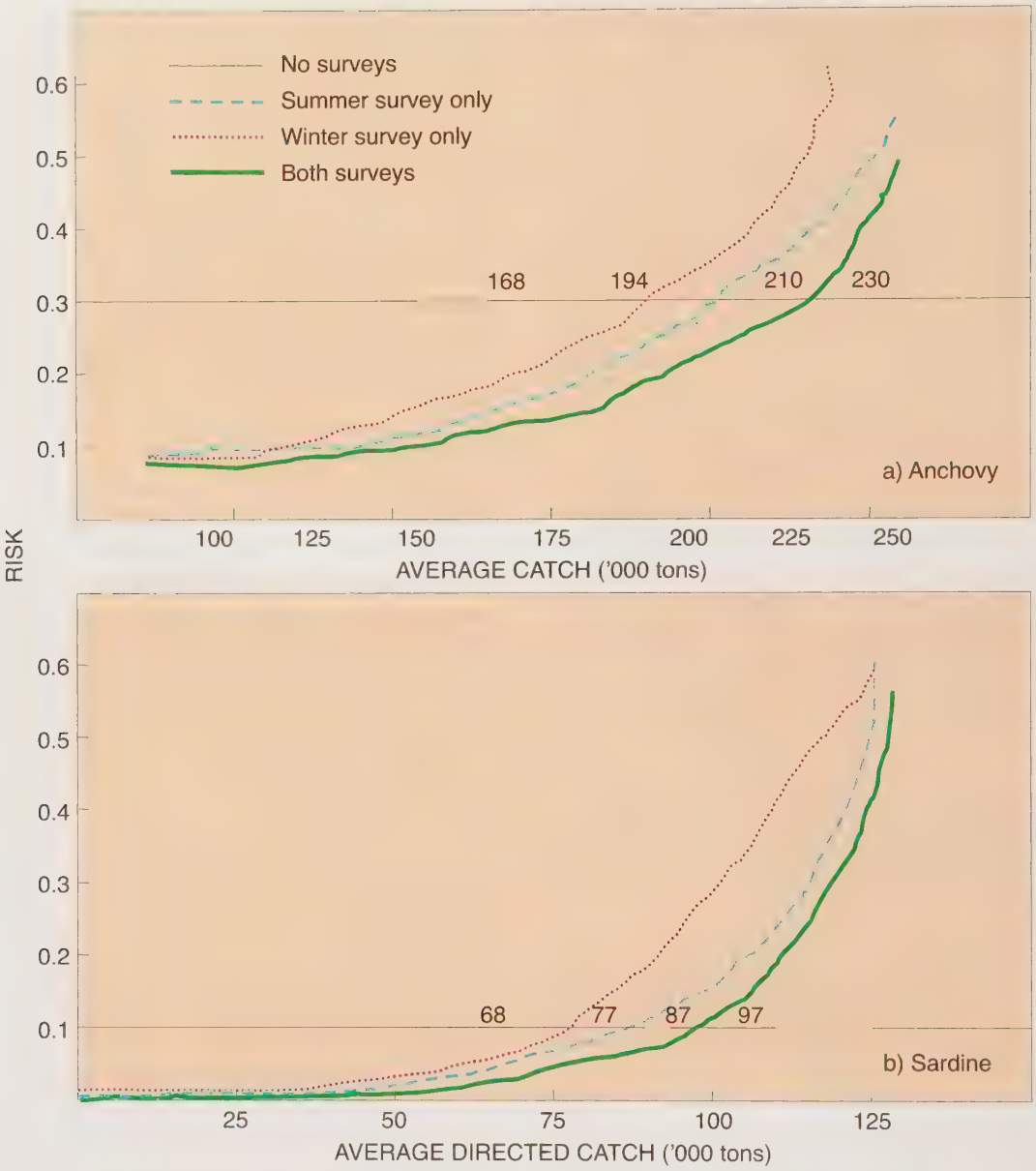

Fig. 31: (a) Anchovy and (b) sardine catch-risk curves, indicating the average catches over a 20-year projection period predicted by the OMP, with and without acoustic assessment cruises

TAC through the by-catch allowance. Basically, it is not possible to maximize catches of both species for as long as their juveniles co-occur in mixed schools, which are targeted by the reduction fishery. Under this scenario, maximization of catches of one species would necessarily limit catches of the other through by-catch limitations. Therefore, catch-*versus*-risk curves are computed under the assumption that there will continue to be a mixed-fishery Industry for the 20-year projection period. The results indicate that the acoustic survey results provide, on average, an additional 29 000 tons of directed sardine per year, or 43% of the average catch without the aid

of surveys (Fig. 31b). According to the mid-1999 wholesale prices of canned sardine, this would be equivalent to R90 million per year.

Many fishery resources worldwide are managed on the basis of commercial data. For this purpose, a number of assumptions are needed, the most important being that commercial catch rates are proportional to stock size. This assumption can be argued against from a number of points of view. Commercial fishers tend to operate in areas of high abundance and certainly become more efficient over time, while many resources are known to reduce their distribution range as their abundance decreases. This is particularly relevant for schooling fish, such as anchovy and sardine. The net effect of these facts is that high catch rates can be sustained in the face of decreasing stock sizes, leading to misinterpretation of commercial catch data and poor management decisions.

The need to monitor pelagic resources closely is further highlighted by the fact that they are subject to large fluctuations in stock size. The main factor responsible for these fluctuations is the state of the environment, which influences pelagic resources through, *inter alia*, starvation, poor spawning conditions, unfavourable transport of spawning products between spawning and recruitment grounds, and predation by birds, mammals and other fish. The impact of these factors is enhanced by the short-lived nature of these pelagic resources, making them vulnerable to a number of continuously evolving factors. Surveys have proved to be an efficient means to monitor these resources, estimate recruitment and understand the dynamics of the resources and the anthropogenic impact on them. In practical terms, they have permitted the fishing Industry to take larger catches in years when recruitment has been good, while protecting the stocks in years of poor recruitment.

A major objective of the newly-implemented Marine Living Resources Act (Act 18 of 1998) is to uphold the principle of sustainable utilization and conservation of our marine resources for the benefit of all South Africans against short-term pressures. This objective can only be achieved through carefully-designed monitoring and assessment programmes. Unfortunately, the human and financial resources required for such a purpose are often jeopardized when pressures to cut costs to the State take precedence over long-term benefits of such programmes. This view is challenged because it is shown above that the current acoustic survey programme for pelagic resources is directly responsible for more than R130 million in fishing products, over and above the amount that would be generated by a fishery managed without independent monitoring systems. The cost of these cruises on the FRS *Africana* is approximately R1.8 million per year, excluding personnel costs, a ridiculously low figure in comparison. To limit survey effort for the sake of saving direct costs to the State would therefore be extremely short-sighted. It is clear that, in order to utilize fully our resources, while simultaneously ensuring their sustainability, the implementation of, and support for, monitoring and assessment programmes should continue.

Fine-scale spatial trends in the distribution of Agulhas sole

Spatial patterns of abundance and biomass estimates of Agulhas sole from four surveys were compared with monthly commercial catch rates (Fig. 32). Peaks in abundance were found either near Cape Infanta (e.g. May 1990) or from the Gourits River to Mossel Bay (e.g. during October 1995, and several other spring surveys); or in both localities, either close to the shore (e.g. April 1996) or further offshore (e.g. April 1993). The major proportion of the annual sole allocation or *TAC* is caught on the trawling grounds between Cape Infanta and the Gourits River. Irrespective of total biomass, the highest monthly commercial catch rates were found to be associated with the highest abundance of sole close to the shore between Cape Infanta and Still Bay, in water deeper than 50 m (e.g. May 1990, April 1996). Because the bay is closed to fishing, high concentrations of sole inside the bay at Cape Infanta may not be reflected in the commercial catch rates (e.g. October 1995).

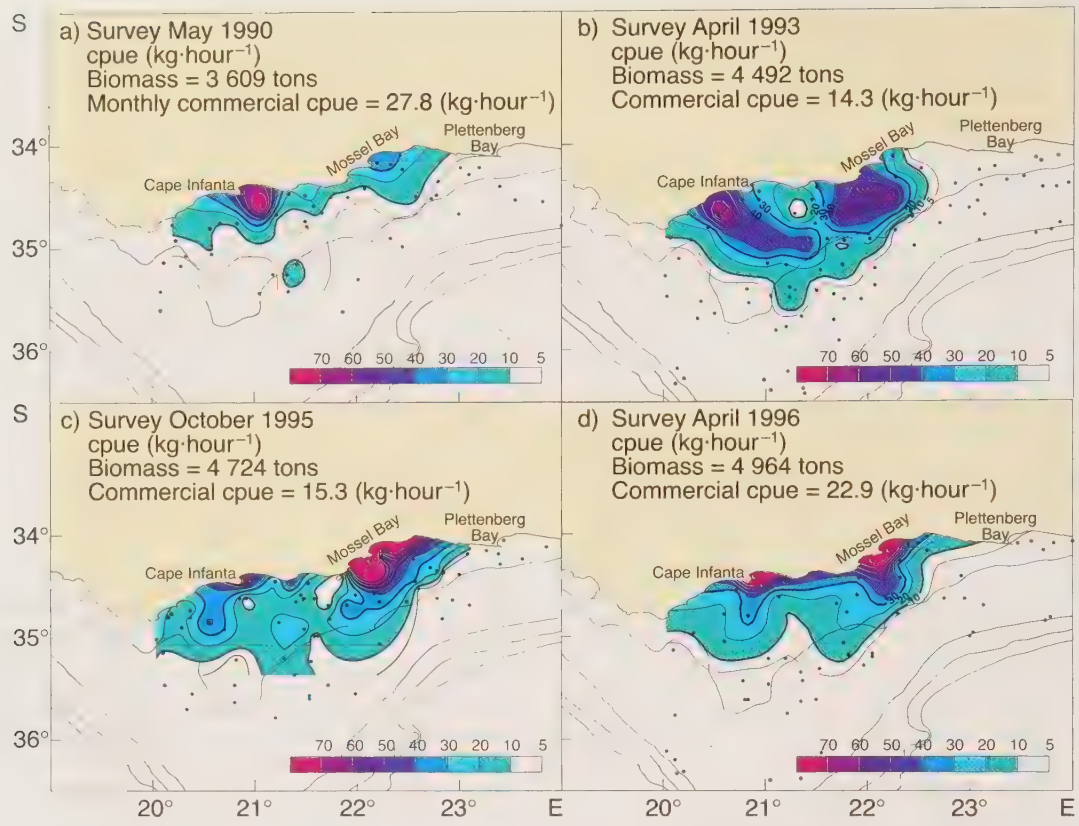

Fig. 32: Spatial variability in abundance of Agulhas sole on the central Agulhas Bank

There was no relationship between monthly catch rates and the estimated biomass during the surveys. Monthly commercial catch rates therefore seem to be influenced by spatial trends in distribution, irrespective of the estimated biomass, which in turn may compromise annual catch rates as annual indices of change in abundance of Agulhas sole. The implication is that, to tune the VPA, more reliance should be placed on survey estimates of biomass than on annual trends in commercial catch rates.

Trends in the sex ratio of Agulhas sole: 1988–1997

To determine spatial trends in sex ratio of Agulhas sole, more than 8 000 specimens from 15 surveys were analysed. The length-frequency distributions of males and females in autumn and spring are shown in Fig. 33a. Few males exceed 40 cm in length, whereas females may achieve 50 cm or more. Males and females of <25 cm are proportionally more abundant in autumn than in spring. Females contribute usually 45–55% in each length-class below 35 cm, becoming increasingly more abundant as their size increases between 35 and 45 cm (Fig. 33b). The proportion of females is higher in deep water (>75 m) than in shallower water as well as on the eastern relative to the central Agulhas Bank (Fig. 33c). There were no significant differences between autumn and spring in male:female ratios, except on the central Agulhas Bank in shallow water (<75 m). If, in some localities, females grew faster and to a larger size than males, spatial differences in sex ratio may have implications for the interpretation of the age-structure of the stock.

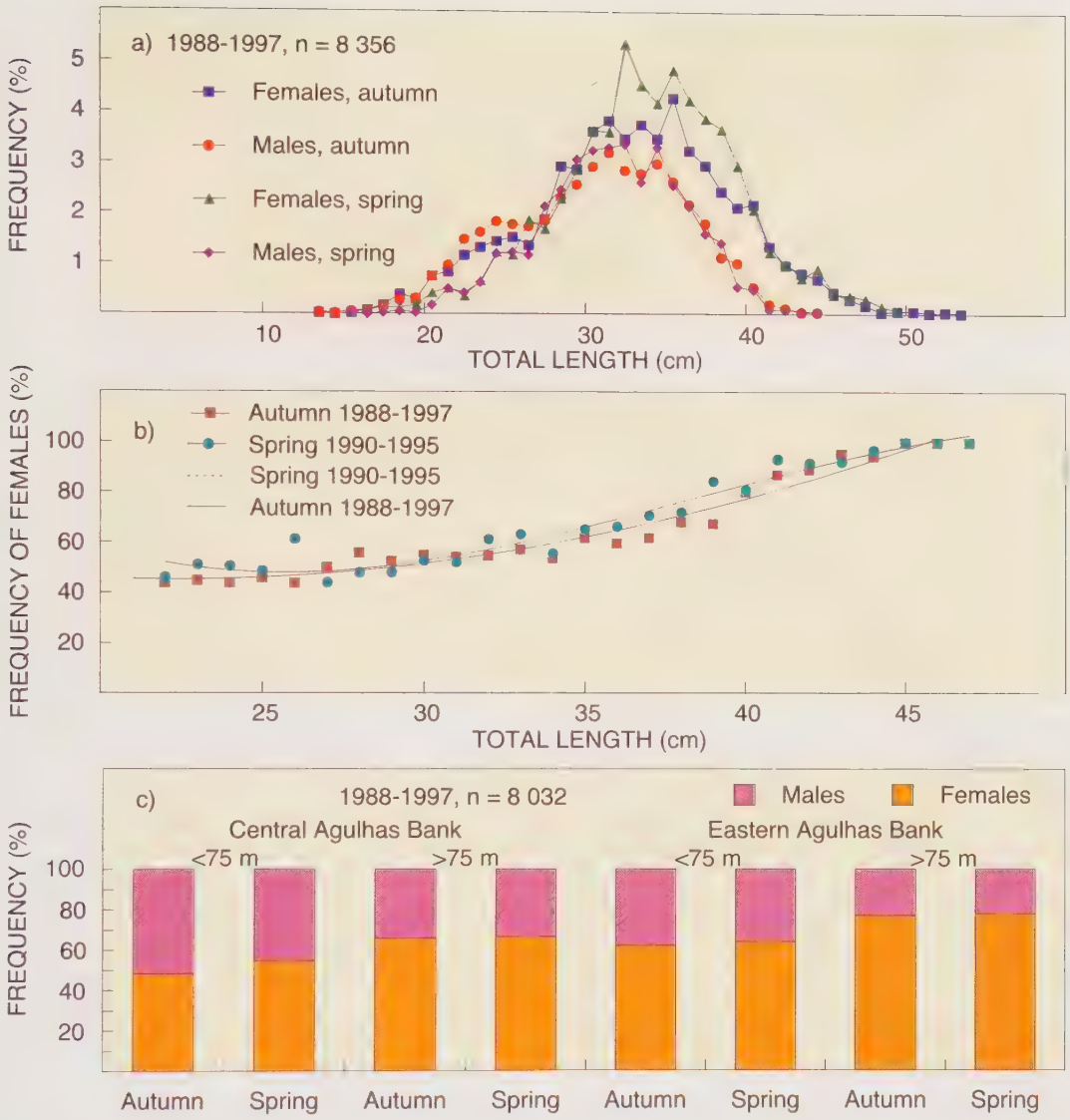

Fig. 33: Trends in the sex ratio of Agulhas sole: (a) length-frequency distribution of males and females in autumn and spring, 1988–1997, (b) percentage females per length-class in autumn and spring, and (c) sex ratios at different depth zones and seasons

Spatial variability in the frequency of mature female Agulhas sole: 1988–1997

The spatial variability in the frequency of mature female Agulhas sole during the period 1988–1997 was examined. For objective comparison over time and space, mature (active to spent) females were defined as those with gonosomatic indices (GSI) of >1% of the expected weight derived from the length-weight relationship. This excluded some females with early-active or spent/resting ovaries. Differences in the frequency of mature females were largely confined to lengths between 25 and 35 cm (Fig. 34). Females matured at a smaller size on the eastern Agulhas Bank than on the central Agulhas Bank, and in shallow water (<75 m) relative to deeper water (Fig. 34). The differences between autumn and spring were

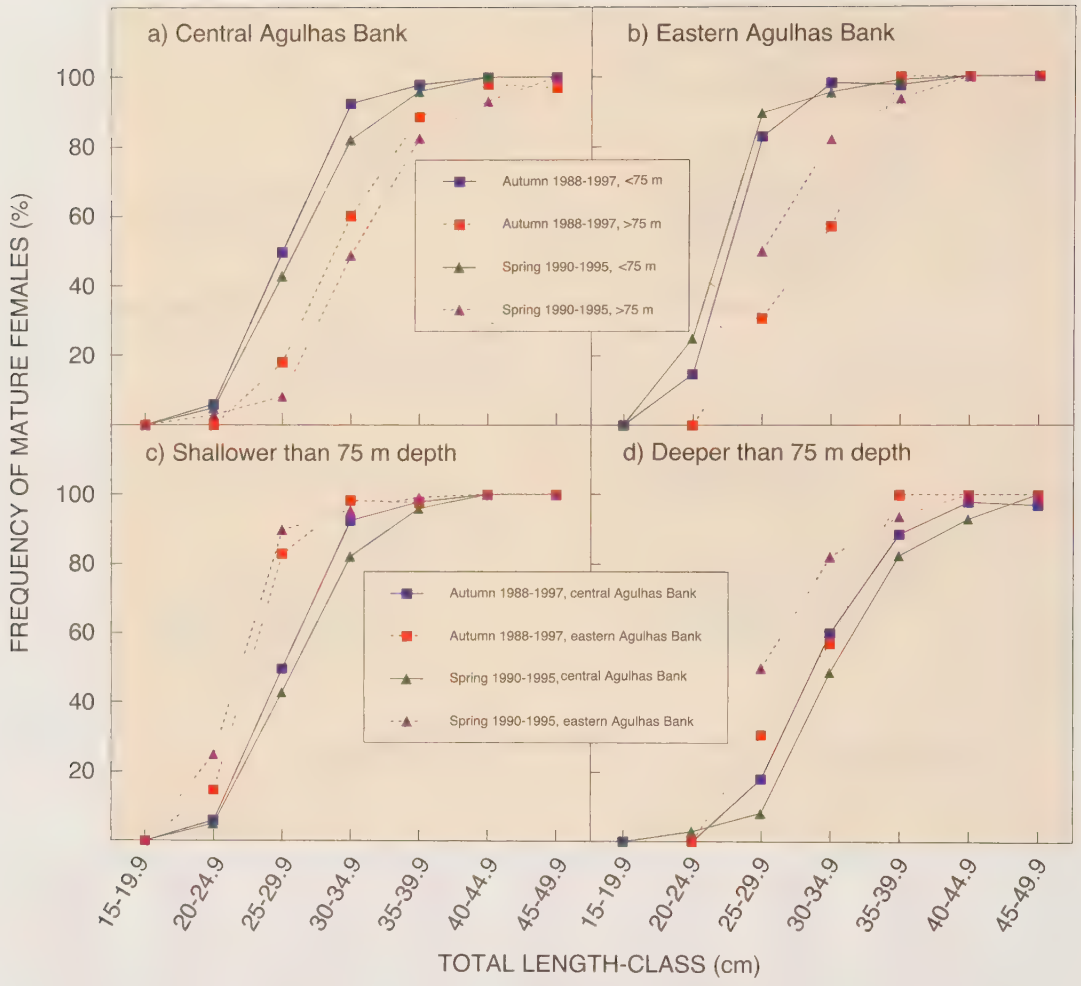

Fig. 34: Spatial variability (locality and depth) in the frequency of mature female Agulhas sole: 1988–1997

generally small, with more females maturing at smaller sizes in autumn than in spring on the central Agulhas Bank, and more females maturing in spring than in autumn on the eastern Agulhas Bank. There were also inter-decadal differences, with more females maturing at smaller sizes during the period 1988–1997 than during 1968–1970 (Fig. 35). The implications of this are that there are differences in reproductive dynamics at different localities and depths, and during different periods, which in turn may influence growth patterns. It is therefore necessary to assess growth patterns from different localities, depths and periods.

Ecosystems approach for pelagic fisheries management: some preliminary results

The need for precautionary management of marine resources is both obvious and crucial for fisheries. Undoubtedly, those having a realistic appreciation of species interactions that occur in the sea have realized that management on a multispecies or ecosystem basis should be the most logical way to proceed. Given the practical and theoretical difficulties involved in such management, the conventional procedures focussing on single species have been a sensible initial

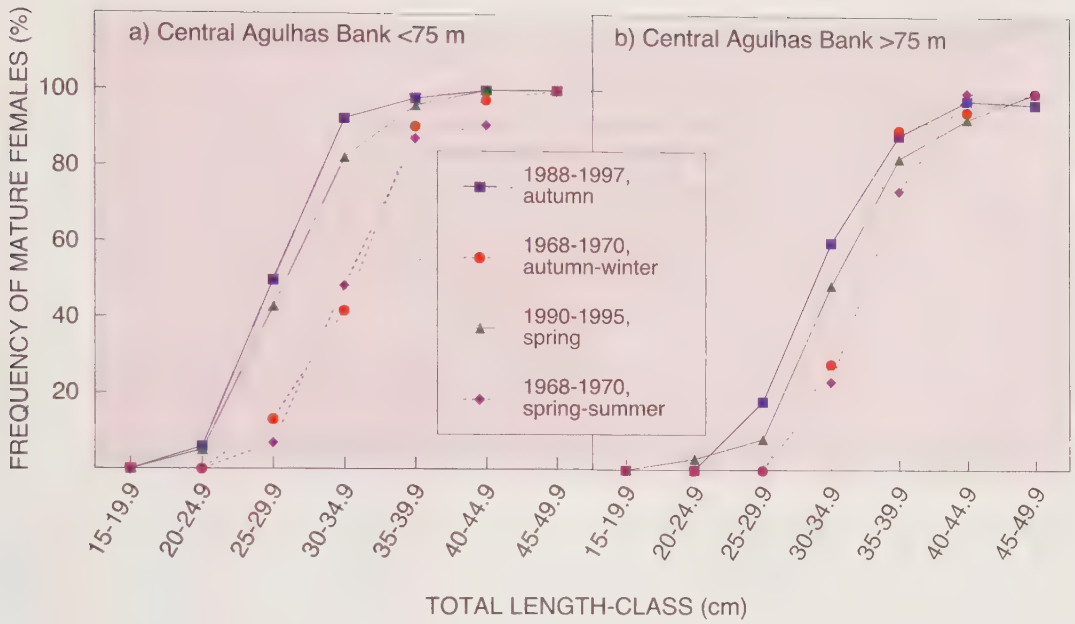

Fig. 35: Variability in the frequency of female Agulhas sole between the periods 1968–1970 and 1988–1997

approach. However, it is becoming increasingly clear that more attention to broader ecosystem aspects is required for fisheries sustainability. This represents a paradigm shift, as well as a new attitude, towards the exploitation of renewable marine resources. However, the ecosystem scale is not one that has received much attention, as management objectives were to sustain the main target species. The ecosystem level should be viewed as an integrative level for ecological studies. For management purposes, this will give new and refreshing insights, which will be essential for achieving political and management goals.

Small pelagic fish are near the bottom of the foodweb and their impact on other species, particularly predators, appears important for the functioning of marine ecosystems. Large catches of highly fluctuating pelagic fish stocks of sardine, anchovy, mackerel and redeye are made in the Benguela. An important question when exploiting these resources is whether these pelagic species are redundant, i.e. do they all have the same impact on other components of the ecosystem?

Using ecosystem models of the southern Benguela system during the 1980s and 1990s, indices quantifying interactions between species and functional groups were developed to explore the functional similarity between small pelagic fish.

The index of interaction strength quantifies the effect that a change in biomass of one group has on the abundance of other groups in a system. Values for the index lie between 1 and 0, with large values indicating that a species (or group) has a stronger impact on other groups than species with smaller values. Of the three most abundant small pelagic fish species (anchovy, sardine and redeye), anchovy were the strongest interactor in the 1980s and redeye in the 1990s (Table 1).

The functional impact index quantifies the impacts of species on their own and other functional groups in the system. Three functional impact (FI) indices were compared: $FI_{pelagics}$ is defined as the relative change in the biomass of small pelagic fish (excluding the species being tested) as a proportion of the relative biomass of the species being tested for its functional impacts; $FI_{zoo.fish}$ is

Table 1: Index of interaction strength in models of the southern Benguela system. Interaction strength is measured when the test group has collapsed through overfishing by year 10, and the system dynamics are simulated for a further 40 years.

Species	1980s	1990s
Anchovy	0.845	0.729
Sardine	0.366	0.686
Redeye	0.818	0.886

the relative change in the biomass of other zooplanktivorous fish as a proportion of the relative biomass of the species being tested; and $FI_{predators}$ is the relative change in the biomass of predators of small pelagic fish as a proportion of the relative biomass of the species being tested for its functional impact.

When fishing pressure on one species is increased, the biomasses of the others within the same functional group increase, and *vice versa*. Anchovy have the largest impacts on their own functional group, whereas redeye have the largest modelled impacts on other zooplanktivorous fish (Fig. 36). The impacts of sardine on zooplanktivorous fish are opposite to those of anchovy and redeye; biomasses of other zooplanktivorous fish increase when sardine fishing mortality is reduced. In contrast, when anchovy and redeye abundances are reduced by heavier fishing, predators switch from anchovy and redeye to a diet consisting of species belonging to the other zooplanktivorous fish functional group, causing a reduction in sizes of these stocks. There are larger differences between the modelled impacts of anchovy, sardine and redeye within their own functional group than on the other zooplanktivorous fish and predatory functional groups. Sardine have stronger impacts than anchovy on their predators.

The functional similarity index quantifies the functional similarity between a species that is removed from a system (e.g. collapsed through overfishing) and other species in the system. It quantifies the extent to which density compensation occurs following a collapse of, or increase in, a target stock.

Most of the simulated density compensation resulting from the collapse of the anchovy stock is by redeye, and *vice versa*. This is reflected in the large functional similarity indices of the two species when the other collapses (Table 2). Both modelled anchovy and redeye are able to proliferate

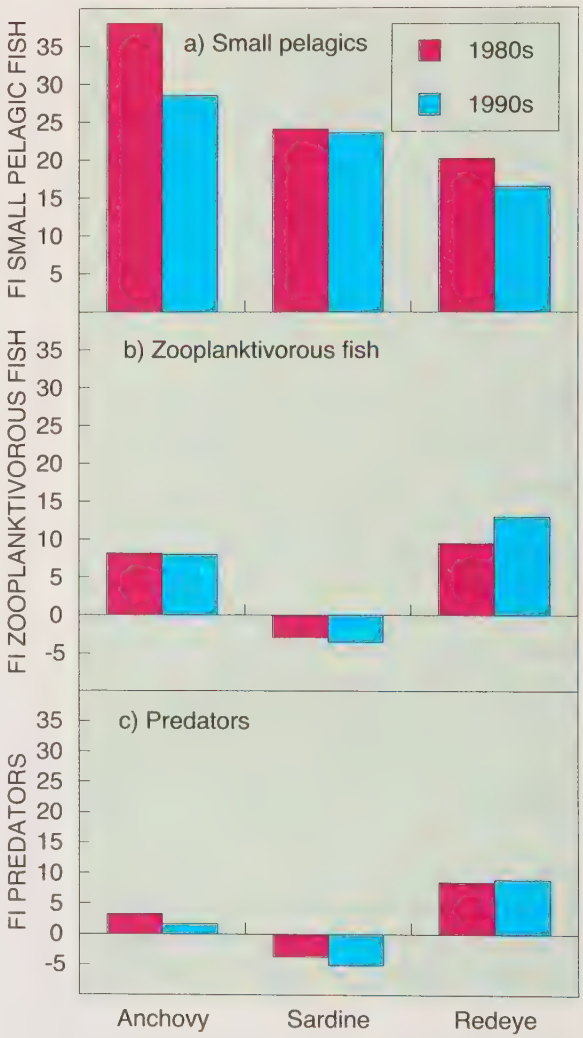

Fig. 36: Functional Impact (FI) indices for (a) small pelagics, (b) zooplanktivorous fish, and (c) predators, derived from simulations of increased fishing mortality eliminating pelagic fish species from the southern Benguela system

Table 2: Functional similarity index in models of the southern Benguela system during the 1980s, when collapses through overfishing of selected groups (columns) are simulated. Strong functional similarity indices are highlighted. "Decreased" indicates groups which do not increase in abundance to fill the empty niche left by the collapse of the group being tested, i.e. they are not considered functionally similar to the test group.

Species	Collapse of anchovy	Collapse of sardine	Collapse of redeye	Collapse of anchovy, sardine, redeye
Anchovy	Collapsed	**0.366**	**0.260**	Collapsed
Sardine	0.022	Collapsed	Decreased	Collapsed
Redeye	**0.413**	**0.212**	Collapsed	Collapsed
Hake	0.050	Decreased	0.075	0.162
Large pelagic fish	Decreased	Decreased	0.010	Decreased
Other small pelagic fish	0.045	0.077	Decreased	0.031
Meso-pelagic fish	Decreased	Decreased	0.083	0.014
Chub mackerel	0.026	Decreased	0.046	**0.110**
Horse mackerel	0.186	0.110	0.070	**0.272**

when sardine are reduced, as reflected in their large functional similarity indices when the collapse of sardine is simulated. A modelled collapse in the redeye stock is not beneficial to sardine, indicating that sardine abundance is not sufficient for the species to compete effectively with other groups (e.g. anchovy) for zooplankton prey made available when redeye collapse. It is likely that sardine are negatively impacted by predators switching to a diet of a larger proportion of sardine than before the elimination of redeye. Therefore, although redeye are able to compensate for a reduction in sardine biomass (i.e. redeye were functionally similar to sardine), sardine cannot be considered to be functionally similar to redeye.

The simplest of indices examined is the index of interaction strength, measuring the relative impact of the demise of a test group on total system biomass. The index is comparable across systems, provided that species aggregations are comparable. For the southern Benguela system, the index shows that anchovy are the strongest interactor in the 1980s and redeye in the 1990s.

The strong similarities in trophic functioning of the southern Benguela system in the anchovy-dominated system of the 1980s, and of the 1990s when there was a shift towards greater sardine abundance, are explained by the functional similarity between anchovy and sardine.

The index that provides the most information on the trophic functioning and interactions between species is the functional impact index. Although actual values of this index are system-specific, the functional impact index may provide information on the relative strengths of the functional impacts of selected species or groups in different systems. It is recommended that this index be the starting point for a working group to develop further indices of ecosystem change and trophic functioning.

Performance of demersal fishing gear

Swept-area trawl surveys are commonly used to estimate the abundance of demersal fish stocks. These surveys could, however, under- or over-estimate the resource because there is an unknown amount of escapement and herding taking place during trawling operations. Consequently, biomass

estimates from swept-area surveys are used as relative indices and not as absolute estimates of abundance.

Another assumption inherent in swept-area surveys is that the catching efficiency of the trawl gear and fish availability to the trawl are constant within and among surveys, i.e. catching efficiency is assumed to be unaffected by substrate type, the weather or the fishing master. Factors that result in random fluctuations in catching efficiency or availability will increase the noise-to-signal ratio in the time-series, whereas factors that are not random, e.g. long-term changes in weather pattern, can introduce bias in the time-series.

Data on gear performance provide an opportunity to test these assumptions and allow effort (and therefore catches) to be normalized should the assumptions be violated. If gear dimensions were highly variable between trawls, the precision of subsequent estimates of density would be influenced, thereby increasing or decreasing the between-trawl variance in density and therefore the coefficient of variation (*CV*) of the biomass index.

During trawling operations, the area swept per trawl is estimated as the product of the length (estimated as trawl duration multiplied by ship's speed) and the width of the trawl track. The fishing master currently estimates the start and end points of the trawl track, and therefore trawl duration. By monitoring the footrope's clearance from the seabed, the start and end points can be determined more precisely. In addition, estimates of the width of the trawl track can be improved by the incorporation of quantitative data on trawl performance. In this way, the use of net moni-

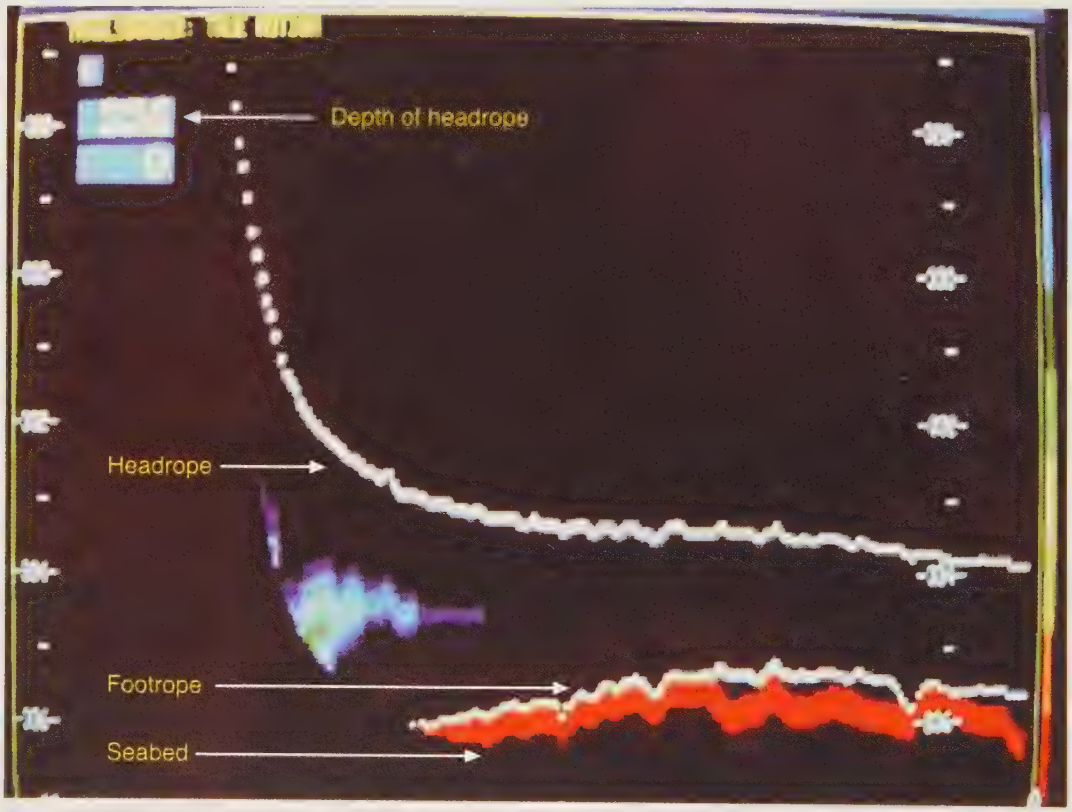

Fig. 37: Scanmar Catch Control System display of in situ *bottom trawl gear performance*

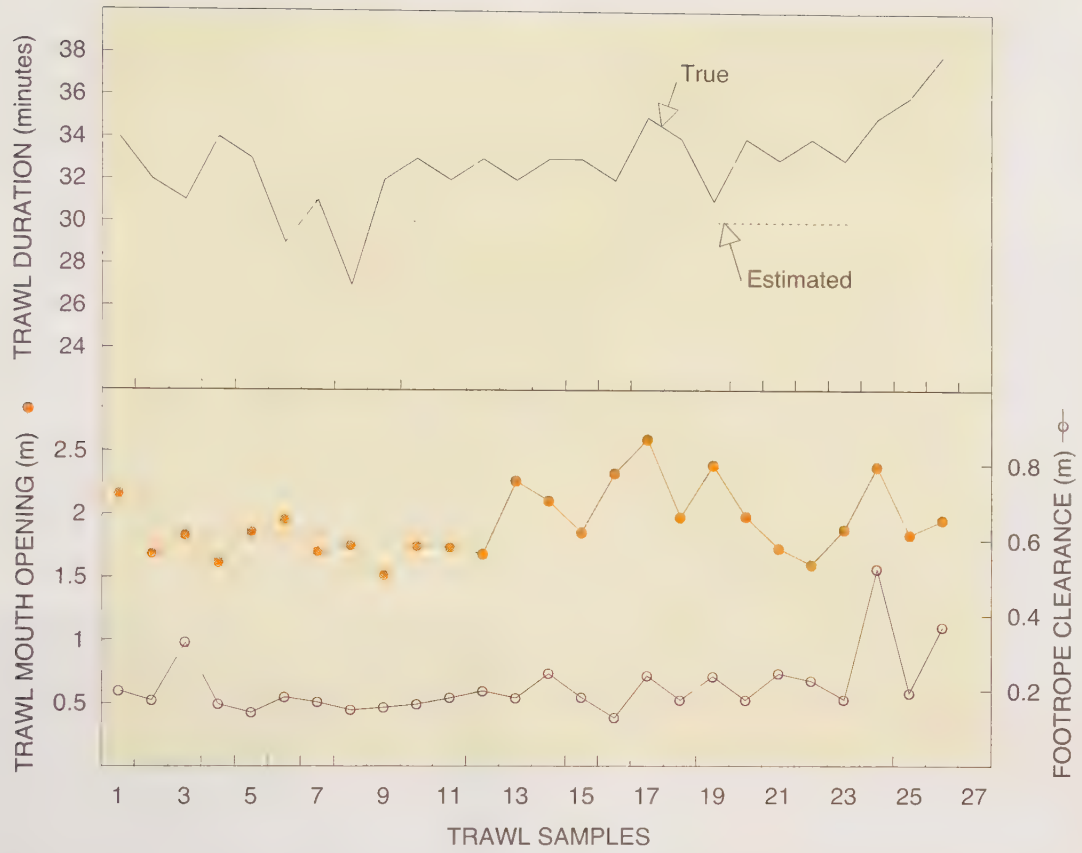

Fig. 38: True and estimated trawl duration (top) and mean vertical trawl mouth opening and mean footrope clearance from the seabed (bottom) of 27 demersal trawls deployed from FRS Africana. *The trawl samples are arranged with increasing depth from left to right*

toring equipment will lead to improved estimates of the area swept.

A Scanmar Catch Control System was used to collect data on trawl gear performance during a standard Demersal Biomass Survey aboard FRS *Africana* in January 1999. Four sensors attached to the gear recorded the depth of the trawl headrope, the footrope clearance from the seabed, the vertical mouth opening and the wingspread of the net. These data were transmitted to a hull-mounted receiver and displayed onboard in real time (Fig. 37).

A comparison between the true trawl duration and the trawl duration estimated by the fishing master is shown in Fig. 38. Generally, trawl duration, and hence the swept area are underestimated by the fishing master. Therefore, fish density and demersal fish abundance are overestimated. For trawls in this study, the *cpue* calculated from the true trawl duration was found to be between 0 and 21% smaller than *cpue* calculated from the estimated duration. Therefore, the cumulative effect over the duration of a survey could result in a marked overestimate of resource abundance.

The vertical mouth opening of the trawl gear (distance between the footrope and the headrope) may also be highly variable. Throughout the trawl sample dataset, vertical mouth openings within each trawl ranged from 1 to 4.1 m, with an overall mean for the dataset of 1.93 m (Fig. 38).

Fluctuations in vertical trawl opening will lead to greater variance in filtered volumes among trawls. Although filtered volumes are not considered important in demersal biomass estimates, variability in vertical mouth opening may influence escapement and hence catches of some species.

If the footrope is not in contact with the seabed, some fish can escape beneath the footrope. The clearance between the footrope and the seabed within each trawl ranged from 0 to 1.4 m, with an overall mean for the dataset of 0.21 m (Fig. 38). Variable clearance between the footrope and the seabed will lead to variable levels of escapement. This will increase the between-haul variability in density estimates, resulting in an increased *CV*.

Data on gear performance enable swept area to be quantified more precisely, leading to improved biomass estimates. These data highlight the need for gear performance to be routinely monitored during Demersal Biomass surveys aboard South African research vessels.

Breeding by swift terns

Swift terns are widespread around coasts of the South-East Atlantic, Indian and West-Central Pacific oceans. The nominate race *Sterna bergii bergii* (Fig. 39) is endemic to southern Africa, numbering about 6 000 breeding pairs. Most of these breed in the Western Cape, where swift terns feed mainly on anchovy *Engraulis capensis* and sardine *Sardinops sagax*. The numbers breeding in the Western Cape have shown wide fluctuations between years, which indicate the dependence of this seabird on a sufficient supply of food.

From 1987 to 1993, the numbers of swift terns that bred were closely associated with the biomass of anchovy measured in November of the previous year by acoustic survey (Fig. 40). Then, from 1994 to 1996, the breeding population of swift terns increased as anchovy decreased. In these years a greater abundance of sardine provided sufficient food for most swift terns to breed. In 1997 and 1998, there was another large reduction in the breeding population of swift terns. In 1997, the biomass of anchovy reached its lowest recorded level since acoustic surveys began in 1984, and the biomass of sardine also fell. In 1999 and 2000, when anchovy and sardine were both plentiful, large numbers of swift terns again bred.

Over the 14-year period of 1987–2000, the numbers of swift terns that bred were significantly related to the combined biomass of these two forage fish species ($r = 0.630$, $p < 0.02$). During this period, swift terns bred at 11 different localities in the Western Cape. Swift terns are nomadic between breeding sites, and not all of the localities are used each year. The mean number of birds breeding at "active" colonies in any year was significantly related to the combined biomass of anchovy and sardine (Fig. 41a, $r = 0.709$, $p < 0.01$).

Fig. 39: Swift tern Sterna b. bergii *(R. Crawford, M&CM)*

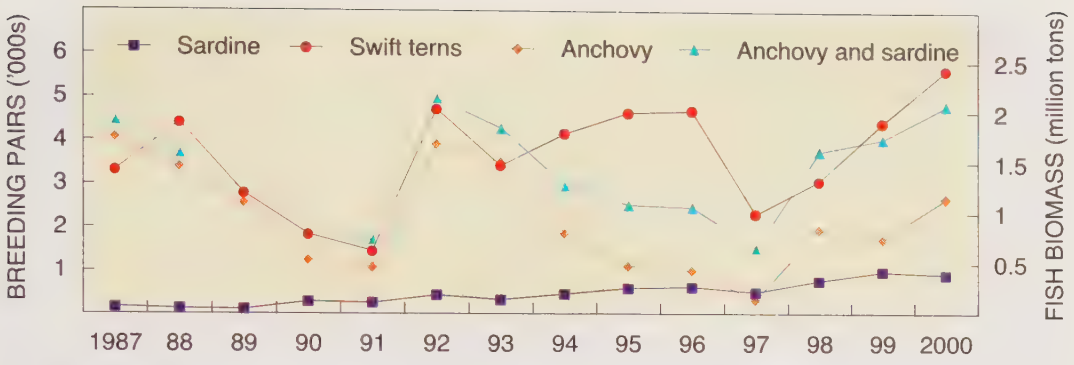
BREEDING PAIRS ('000s)
FISH BIOMASS (million tons)
Sardine
Swift terns
Anchovy
Anchovy and sardine
1987 88 89 90 91 92 93 94 95 96 97 98 99 2000

Fig. 40: Number of swift terns breeding in the Western Cape compared with the spawner biomass of anchovy, of sardine and of these species combined, 1987–2000

At localities, swift terns often breed in several discrete colonies. The mean size of colonies also was significantly related to the combined biomass of anchovy and sardine (Fig. 41b, $r = 0.789$, $n = 13$, $p < 0.002$). This indicates that in years of food scarcity, the density of food is insufficient to support large aggregations of breeding birds. Since 1987, breeding aggregations in the Western Cape have ranged from solitary pairs to about 3 000 pairs. Swift terns carry food from feeding grounds to their chicks in their bills and to do so they require a ready supply of food around breeding localities.

The variable distribution of the pelagic fish on which they prey is probably the primary factor influencing the selection of breeding localities by swift terns. These suitable localities will vary from year to year in accord with where food is plentiful at the time. Also, there is evidence that the presence of mammalian predators causes swift terns to abandon breeding localities. Feral cats *Felis catus* increased to such an extent at Robben Island that no terns bred there in 1998. More than 100 cats were removed from this island in the summer of 1998/99 and more than 1 100 pairs of swift tern returned to breed there in the autumn of 1999. Cats probably caused swift terns to abandon Lambert's Bay after 1997. Excessive human disturbance similarly may cause abandonment of breeding localities.

The fact that swift terns move between breeding localities means that, once they have found a locality where there is adequate food nearby, they will look for a safe breeding site. Breeding by other species of seabird will be an indication that a site is safe. Therefore, in the Western Cape, swift

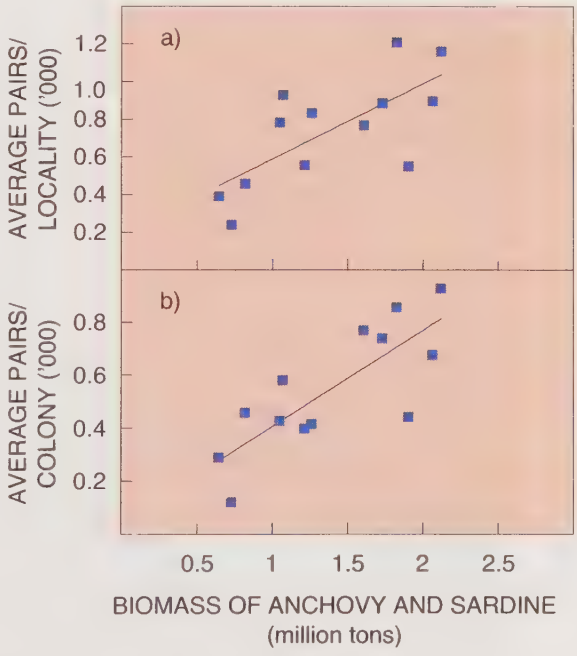

Fig. 41: The relationship between the combined biomass of anchovy and sardine and (a) the mean number of swift terns breeding at "active" localities and (b) mean colony size, 1987–2000, excluding 1988 when not all breeding localities were visited

terns usually breed in association with other species. Between 1987 and 2000, they bred alone in only 17% of breeding attempts. In 77% they bred in association with Hartlaub's gull *Larus hartlaubii* and in 18% in association with crowned cormorant *Phalacrocorax coronatus*. They occasionally also bred with greyheaded gull *L. cirrocephalus* and roseate tern *S. dougallii*. Other seabirds also may be seeking safe sites, and sometimes join with swift terns that have initiated the breeding.

Long-term ringing has shown that swift terns move between breeding localities. Of birds whose colony of origin was known, only 19% of those breeding and 28% of those present at colonies were at their natal localities. The others has moved to different localities. Most cohorts bred at several localities during their lifespan, and breeding at most colonies in a given year is by birds that have fledged at several localities.

In 2000, a 21-year-old swift tern was observed breeding at Dassen Island. This is the oldest record for this species worldwide. There is a total of 95 records in South Africa of swift terns alive at age 15 years or older.

Swift terns in the Western Cape first breed when aged 3 years. Although a few younger birds may be present at breeding localities, swift terns may not be fully recruited to breeding colonies until they are 5 years old (Fig. 42). In periods of food shortage, age-at-first-breeding may be deferred by up to two years. It is more important for inexperienced adults to remain alive than to jeopardize their survival by attempting to breed when food is scarce.

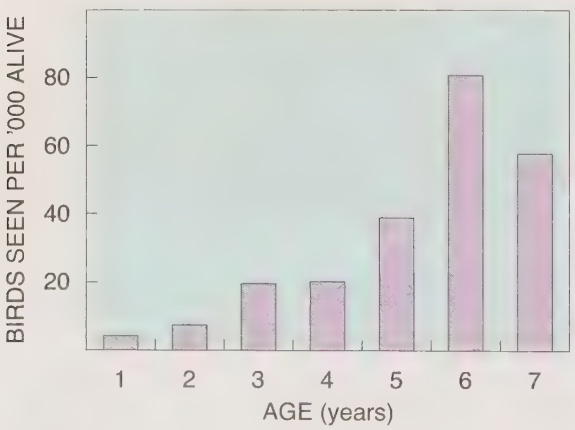

Fig. 42: Proportions of colour-banded birds aged 1–7 years estimated to be alive that were seen at breeding colonies, 1995–2000

Research in the Southern Ocean

Research in the Southern Ocean is undertaken by M&CM in support of South Africa's obligations to the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). This research is divided into three major components, which provide input into the CCAMLR Ecosystem Monitoring Programme (CEMP) and underpin the management of exploited stocks.

The first component focusses on the resource potential and management of Antarctic krill *Euphausia superba*. In cooperation with scientists at UCT, M&CM staff remain in the forefront of developing models of krill spatial distribution as a basis for managing the Antarctic krill fishery and in the study of krill predator-prey relationships. Work is continuing in this field and there has been further development of a one-way model to describe possible functional relationships between harvesting activities and the population dynamics of selected krill predators. Work on factors inducing krill aggregation formation, maintenance and dispersal continues. Results from these studies were presented as a keynote address at the "Second International Krill Symposium" held in the United States in August 1999. In addition, during early 2000, M&CM scientists (along with colleagues from Japan, Russia, the United Kingdom and the United States) participated in the largest survey of krill to be undertaken in the Western Atlantic since 1981. The results from this survey will be used by CCAMLR to assess krill yield in the region and have provided input to a study being undertaken by the Industrial Development Corporation on the feasibility of a locally-based krill fishery.

Fig. 43: Five of the burrowing seabirds present at Marion Island: (a) greatwinged petrel, Pterodroma macroptera *(b) Softplumaged petrel* Pterodroma mollis, *(c) blue petrel* Halobaena caerulea, *(d) Salvin's prion,* Pachyptila salvini *and (e) Kerguelen petrel* Pterodroma brevirostris *(B. M. Dyer, M&CM)*

The second area of Southern Ocean research relates to the management of the longline fishery for Patagonian toothfish (*Dissostichus eleginoides*), particularly in the vicinity of the Prince Edward Islands. Data collected from an integrated monitoring scheme, using scientific observers and satellite-tracking, are submitted to CCAMLR and used in setting catch limits for the region as a whole. However, both the national and the CCAMLR toothfish fishery continue to suffer from high levels of illegal, unregulated and unreported fishing. The impact of these activities has been so marked that *cpue* for toothfish in the Prince Edward Islands Economic Exclusion Zone (EEZ) has dropped dramatically over the past three years and in cooperation with UCT's Department of Applied Mathematics, a model is being developed to examine possible future trends in the toothfish population around the Prince Edward Islands. It is also envisaged that a fisheries-independent monitoring survey of toothfish stocks around the islands will be undertaken in the near future.

Seabird research forms the third component of Southern Ocean research. From 1995 to 2000, seabirds that nest in burrows (Fig. 43) at Marion Island were investigated. Areas having different topography and vegetation types were visited on a regular basis. The rates of return of different species to these areas were established and will serve as a bench mark against which it is hoped that any future changes in populations can be assessed, although numbers of birds sighted were influenced by both weather conditions and season (Fig. 44). The observations were conducted at night using a spotlight because many of the birds return to the island only during darkness. During daylight these birds are preyed upon by seabirds.

The burrowing bird seen most often during the five years of observations was Salvin's prion *Pachyptila salvini*, followed by greatwinged petrel *Pterodroma macroptera* (Fig. 44). In all, 17 538 individuals representing 13 species of burrowing seabird were identified during a total of 396 hours of observations. Additionally, 14 563 birds that were not identified to species level were recorded during

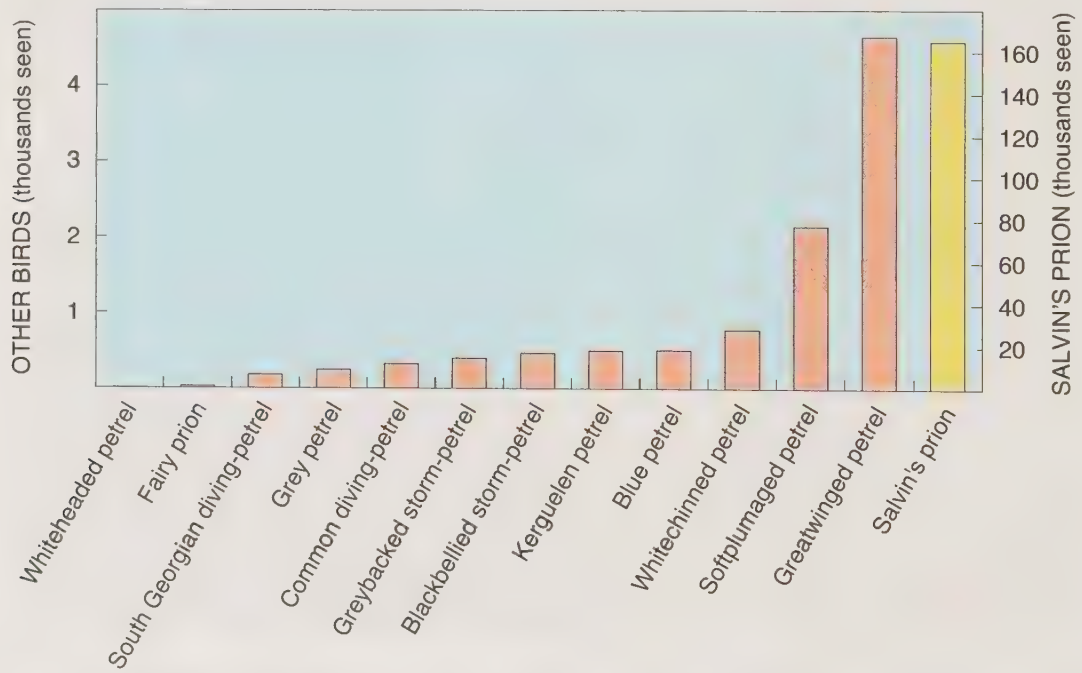

Fig. 44: Numbers of burrowing seabirds recorded at Marion Island during systematic observations conducted over a five-year period between 1995 and 2000

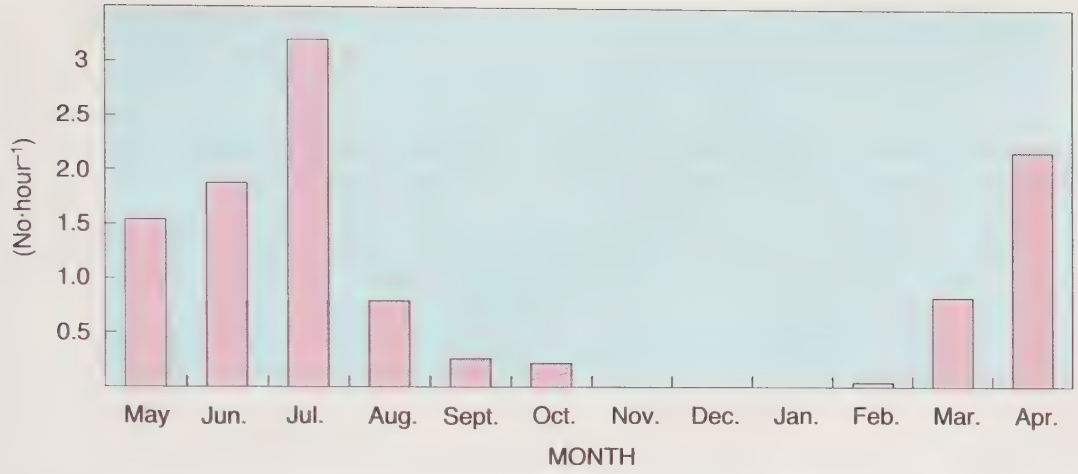

Fig. 45: Seasonal trend in the number of greatwinged petrel recorded per hour at Marion Island, 1995–2000

observations. The seasonal patterns of occurrence of the two species most commonly encountered are shown in Figs 45 and 46.

Greatwinged petrels were only observed between February and October, and were most frequently seen between April and July (Fig. 45). The species is an autumn-winter breeder that at Marion Island lays eggs in late May. At other localities, immature birds and non-breeders leave colonies from August through October, and breeders and fledglings from November through January. The seasonal pattern at Marion Island appears similar. Birds return to Marion Island from February to April.

Salvin's prion is most conspicuous at Marion Island from July to October and from December to February (Fig. 46). The rate of encounter of birds at the island is considerably less from March to June and during November. Laying takes place in the last half of November. Hatching is in the first half of January and fledglings depart during late February and early March. It appears that

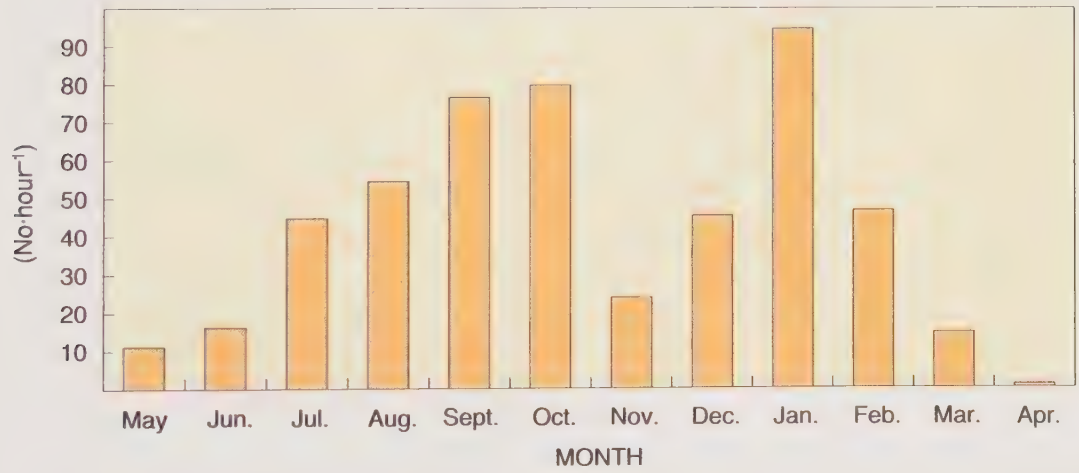

Fig. 46: Seasonal trend in the number of Salvin's prion recorded per hour at Marion Island, 1995–2000

many of the parents leave the island once chicks have fledged and start to return from July onwards. At Isles Crozet to the east, the return is later, in September. Birds remain at Marion Island for a two-month period, from September to October before, as at Isles Crozet, undertaking a pre-laying exodus in November. During December, when birds are incubating eggs, they are less visible than in January, when they are provisioning chicks. This is expected as the mean length of incubation shifts is 6.5 days, whereas chicks are fed at intervals of about 1.75 days.

TECHNOLOGICAL ADVANCES

New vessel monitoring system for M&CM

South Africa is following the worldwide trend by real-time monitoring of fishing vessels operating in its EEZ. At present all foreign fishing vessels and selected local longline vessels are required to have vessel monitoring systems (VMS) onboard. Should South Africa decide to follow the European Union's example to make VMS compulsory for all vessels over 24 m, M&CM's new VMS would be up to the task. M&CM obtained the Racal Locator VMS base station in February 2000 to enhance its offshore compliance capacity. This system offers near-real-time vessel monitoring and reports the vessel's position, course and speed (including the status of the Automatic Location Communicator). The system can utilize both INMARSAT C and ARGOS satellite technologies to achieve maximum coverage of the ocean surface.

The new VMS offers the following advantages over the previous base station:

- Reporting via Data Network Identity (DNID) promotes flexibility and reduces overall communication costs of the system.
- Reporting configurations can be updated remotely on INMARSAT C units. This includes reporting periods and initial configuration of units.
- Data are stored on an Oracle database, ensuring a high level of security of the data. Users can also be allocated appropriate security levels.
- Data received cannot be edited by operators.
- Data are encrypted and communication is via the Wide Area Network (WAN).
- The VMS server has several fail-safe mechanisms (such as back-power supply) to ensure 24-hour operations.
- Work stations can be added to suit the Operations Room's needs and remote work stations can be added via secure WAN.
- The system can accommodate large numbers of vessels and has the additional capacity should M&CM require monitoring of extra vessels. (A similar system currently installed in the USA will be tracking >10 000 vessels.)
- The base station is automated to reduce operator workload and warning alarms can be forwarded via e-mail, fax and SMS (cell phone)
- The history of vessel activities can be displayed as a track on vector charts (C-MAP, WGS 84 datum).

The new VMS will enable "smart zones" to be created. The "smart zones" can be programmed to monitor, for example, the speed of a vessel. Such zones are useful in marine reserves or fishing-exclusion zones. Additional zones can be placed at discharge points, notifying the operator when selected vessels enter these areas. In the case of quota-controlled species, it will enable better deployment of the Inspectorate services.

The flexibility of the system enables group management of vessels which will provide simultaneous configurations of, for example, a selected fishing sector.

The new VMS base station will increase the monitoring control and surveillance capacity of M&CM and will promote better cooperation with role players tasked with protecting the EEZ.

Advances in hydro-acoustic research

The development of fish identification techniques based on hydro-acoustic data is receiving priority attention throughout the world's acoustics community. It is accepted that incorrect identification of acoustic targets is a key error in biomass estimation. At present this identification relies heavily on ground-truthing by aimed trawling and visual interpretation of the echograms. Often, however, these techniques do not allow

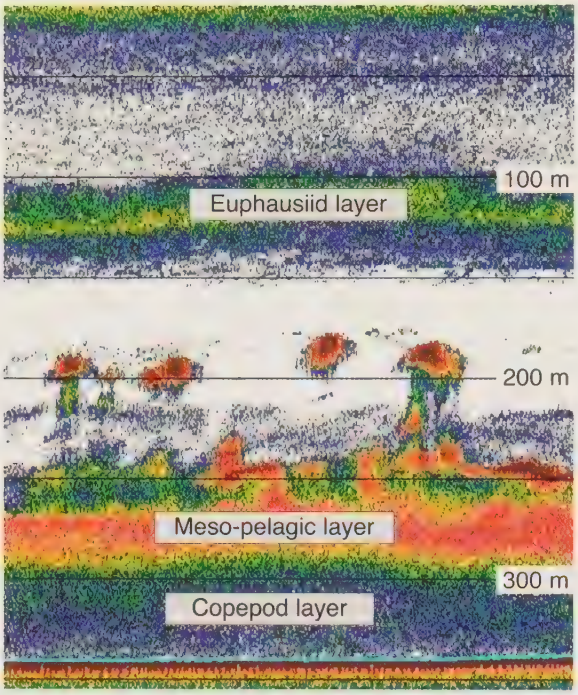

Fig. 47: A section of echogram showing the different scattering layers in the water column during the day.

unbiased discrimination between co-occurring biological sound scatterers.

A new approach used to address this problem is the use of multi-frequency methods. Acoustic theory predicts that broad organism-types have a specific acoustic signature at different sound frequencies, depending on their size, shape and other scattering properties. It may therefore be possible to use acoustic signatures at more than one frequency to identify the main scattering organisms.

Experimental acoustic data have been collected at frequencies of 18, 38 and 120 kHz and although analysis of these data is ongoing, preliminary results look promising. Initial investigations into the sound-scattering properties of scattering layers revealed significant differences in mean acoustic back-scattering strength of organisms at at least one of the frequencies used. The three scattering layers investigated consisted of euphausiids, meso-pelagic fish (mainly lightfish) and copepods (Fig. 47). Organisms were identified during a series of Multinet tows

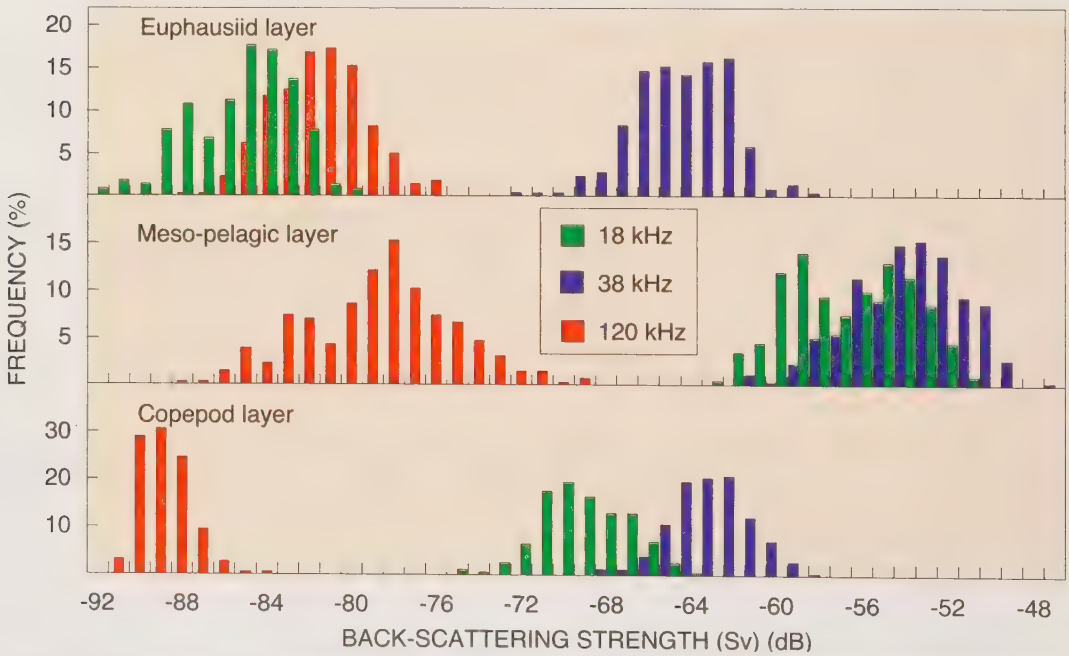

Fig. 48: Frequency distribution plots of acoustic back-scattering strength (Sv) for each frequency within the selected layers

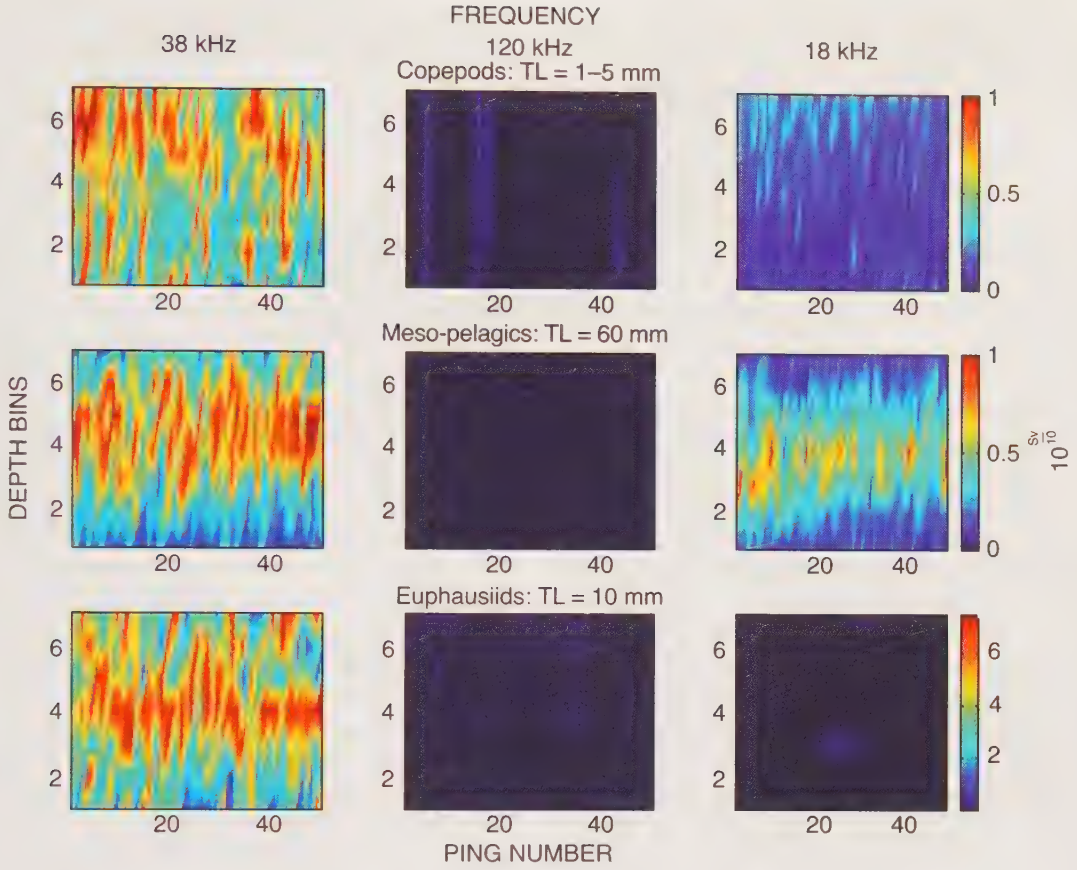

Fig. 49: Re-generated echograms, after correction for beam width and pulse length effects, at each of the three frequencies for each of the selected layers

throughout the water column and midwater trawling. Substantial corrections were applied to the raw acoustic data to account for differences in beam width of the transducers and pulse-length effects. The corrected distributions of acoustic back-scattering strength (*Sv*) for each of the layers at the three nominal frequencies (Fig. 48) showed weak signals for all three sound-scattering layers at 120 kHz. At 38 kHz the acoustic signatures were similarly strong for all three layers although the back-scattering strength was highest for meso-pelagic fish. The most significant and discriminatory difference was seen at 18 kHz with three distinct peaks in the distribution of back-scattered energy for each of the sound-scattering layers. Re-generation of the echograms from the corrected acoustic data displays these differences very clearly (Fig. 49). A basic pattern emerges which effectively discriminates between the sound-scattering layers, i.e. meso-pelagic lightfish are highly visible at both 38 and 18 kHz, whereas copepods are highly visible at 38 kHz, and only slightly visible at 18 kHz; euphausiids, however, are only visible at 38 kHz. Further ground-truthing of these results and that of other scattering layers is necessary. Another advantage of using a multi-frequency hydro-acoustic system is that it will allow discrimination not only between scattering layers but also between schools of pelagic fish during the day. This could increase the accuracy of acoustic surveys by improving acoustic target identification.

M&CM RESEARCHERS IN THE INTERNATIONAL ARENA

The research staff of M&CM continued to represent national interests on several international fora. Fostering these international relationships fulfils national obligations to international research and management agreements. South Africa remains at the forefront in marine resource management and research, internationally and particularly regionally, through actively participating in these partnerships.

These international fora include, *inter alia*, IWC (International Whaling Commission), CCAMLR (Commission for the Conservation of Antarctic Marine Living Resources), ICES (International Council for the Exploration of the Sea), IOC (Intergovernmental Oceanographic Commission of UNESCO), ICCAT (International Commission for the Conservation of Atlantic Tuna) and ISOM (International Ships Operators Meeting). At national level, M&CM has provided advice to delegations at the CSD (Council on Sustainable Development) and the CBD (Convention on Biodiversity). Over the past year, it has also assumed responsibility for implementing relevant sections of the UNCLOS (United Nations Law of the Seas) locally and for national acceptance of the UNIA (United Nations Implementing Agreement for the Provisions of UNCLOS Relating to the Conservation and Management of Straddling Fish Stock and Highly Migratory Fish Stocks, the FAO Compliance Agreement and the FAO Code of Conduct for Responsible Fisheries).

International seaweed research collaboration

The value of KwaZulu-Natal's (KZN) marine biodiversity has long been realized, but the marine macroalgae are one of the groups of organisms that are very poorly studied taxonomically, and consequently largely ignored in ecological studies. This has been frustrating for KwaZulu-Natal's Nature Conservation Services (KZNNCS) biologists who are trying to document the biodiversity of this coast for management purposes, and for phycologists seeking to understand the distribution and ecology of these organisms in KZN. In 1999 a KZN seaweed biodiversity project was started, involving collaboration between the State University of Ghent (Belgium), UCT, and the M&CM Seaweed Unit, with some logistical support from KZNNCS. The project is funded by the government of Flanders and the National Research Foundation (NRF), and aims to improve our understanding of the systematics, biogeography and ecology of the KZN seaweed flora. So far, about 1 500 specimens have been collected, representing at least 500 species, including about 50 new records for South Africa and several species new to science. The information from the project is proving to be of great interest to scientists as well to managers of MPAs.

Capacity building in the field of seaweed biodiversity

Senior students from the universities of Fort Hare, Transkei and the Western Cape participated in a week-long seaweed biodiversity trip to the Kei mouth area of the Eastern Cape in October 1999, as part of a Dutch-funded collaborative project with UCT and the M&CM Seaweed Unit. The project aims to build capacity among students from Historically Black Universities. Students learnt the basics of macroalgal identification from internationally-recognised taxonomist, Dr Herre Stegenga, and made their own reference collections. Discussions on biogeography and shore ecology were led by UCT and M&CM scientists. One student (from Fort Hare) then returned to Cape Town to spend

a month analysing the seaweed collections under the supervision of Dr Stegenga. The information and specimens collected form part of our continuing effort to document the biodiversity, biogeography and ecology of seaweeds of the South African coast, and several publications are expected to result from this trip. This project is funded by SANPAD (SA-Netherlands Programmes for Alternatives in Development).

VIBES

The collaborative research programme between French and South African scientists known as VIBES (VIability of exploited pelagic fish resources in the Benguela ecosystem in relation to the Environment and Spatial aspects) entered its second phase in 1999, and continues to develop as a strong scientific partnership between the two countries. Directed towards providing new tools and information for the regional assessment and management of coastal pelagic resources in the Benguela, the main objectives of VIBES are to study long-term changes in fisheries, pelagic fish recruitment and spatial patterns in relation to the environment, and adult fish abundance according to different scales of observation. The first phase of this programme concentrated primarily on retrospective analysis, whereas the second has focussed on physical and ecological modelling. Substantial progress has been made during the past year, including:

- the development of a three-dimensional hydrodynamic model (known as PLUME) covering the continental shelf off the west and south-west coasts of South Africa, which aims to simulate in time and space the dynamics of the environment within the southern Benguela ecosystem;
- retrospective analyses of fishery data and satellite data; the development of a pelagic fishery GIS which incorporates fishery, acoustic and environmental data; and
- training of a number of local and foreign students, including four each at the Honours and M.Sc. levels, and one at the Ph.D. level.

IDYLE

Following restructuring at the Research Institute for Development (IRD, formerly known as ORSTOM), French and South African scientists involved in VIBES have developed an IRD Research Unit named IDYLE (Interactions and Spatial Dynamics of Renewable Resources in Upwelling Ecosystems) to follow the VIBES programme that will end in 2001. This Research Unit involves several partners from the Benguela region and the IRD, as well as from French Universities, and is aimed at strengthening the cooperative work initiated during VIBES I and II. An important focus of IDYLE is modelling and research will partly concentrate on the development of models initiated by VIBES II, such as an Individual-Based Model (IBM) that will enable a better understanding of the coupling between the dynamics of the physical environment (from the PLUME model) and the early life-history stages (eggs and larvae) of pelagic fish. IDYLE will also incorporate some new research directions, in particular a marked orientation towards an ecosystem approach. The approaches implemented, models developed and display tools used by VIBES-IDYLE will be made as generic as possible, in order to permit the rapid transfer of these methodologies and results to other ecosystems. A substantial training component will allow young scientists from the region to further develop these tools for management.

Harmful algal blooms

Scientists from M&CM have contributed to the establishment of a new international programme GEOHAB – Global Ecology and Oceanography of Harmful Algal Blooms (HAB) – formed jointly under SCOR (Scientific Committee on Oceanic Research) and IOC sponsorships. Acknowledging that the harmful algal problem is global, the GEOHAB programme has as its core mission: to foster international cooperative research on HABs in the context of their ecological systems and the oceanographic processes which influence them. An M&CM scientist is a member of the GEOHAB

Scientific Steering Committee which has been responsible for writing the Science Plan. Five key areas to be addressed by GEOHAB include: changes in HAB species distribution and biodiversity; adaptive strategies for HABs; HABs and eutrophication; ecosystem studies; and observation, modelling and prediction of HABs.

Benguela Current Large Marine Ecosystem Programme (BCLME)

After protracted international and national workshops and meetings a Strategic Action Plan was signed by the five relevant Ministers in South Africa, Namibia and Angola to undertake a joint Large Marine Ecosystem Study under the GEF/UNDP International Waters Programme. This ambitious programme, built on the initial success of the BENEFIT programme, focussed on fish and the environment, but encompassed larger-scale features of the Benguela, including the tropical Atlantic and Agulhas Current influences, as well as coastal zone management, pollution and offshore mining activities. A project proposal was submitted to the GEF in December 1999 and approval was granted in June 2000, subject to some minor alterations. The initial request should generate some US$12 million of incremental funding over five years for the three countries and a further US$2.2 million for management costs, providing a major boost to the management of the Benguela system as a whole. A Transboundary Diagnostic Analysis developed during 1999 identified the major issues and possible solutions, and multidisciplinary studies should be initiated in 2001.

Living Marine Resources Panel of the Global Ocean Observing System (LMR-GOOS)

A senior scientist from M&CM participated on this panel which was required to devise a monitoring system for the living marine resources of the world ocean, focussing on the open ocean and coastal shelf areas but largely excluding the very nearshore environment, which includes coral reefs, mangroves, rocky shores and estuaries. A Strategic Design was developed showing typical examples of the sort of monitoring programmes which could be conducted in upwelling systems, enclosed seas, the open ocean and in temperate zone shelf regions. Emphasis was placed on practicality of monitoring and the need to employ modern technology to monitor at appropriate time and space scales. Adequate monitoring is seldom achieved in third-world or developing countries as the complexity and diversity of the living marine resources and the inherent variability of ecosystems require monitoring programmes beyond the scope of many countries in terms of financial and human resources. Nevertheless, these deficiencies need to be acknowledged and addressed and the aim of the panel was to suggest a generic set of observations and indices which can be the objectives of capacity-building and development programmes.

Envifish

The European Union-funded Envifish project involving six partners from Europe and four partners from the countries adjacent to the Benguela Current upwelling area (South Africa, Namibia and Angola) is currently in the second year of the three-year project. South Africa is represented by both UCT and M&CM. The main objective of Envifish is to develop appropriate methodologies for improving the sustainable management of small pelagic fish in the region. This will be done through studies focussing on the identification and quantification of key environmental variables that influence fluctuations in the recruitment and distribution of the main pelagic species in the Benguela and Angola current systems. Since the project was launched various products documenting key environmental variables and life histories of the small pelagic species in the region have been produced. A set of calibrated sea surface temperature satellite images extending from 1982 to 1995 have been distributed to project partners and other researchers investigating recruitment variability of small

pelagic fisheries in the Benguela region. As is the case with other international partnerships Envifish is focussed on the building of capacity in the region and supports one student at the M.Sc. level and one at the Ph.D. level.

The 1999 BENEFIT Research Training cruises

M&CM is committed to regional collaboration on the management of marine resources through research and capacity building. A prime example is BENEFIT which has been approved at ministerial level by the three partner countries. The programme involves Angola, Namibia and South Africa, the Southern African Development Community (SADC), and various overseas collaborator and sponsor institutions. In 1999, M&CM provided sea time on its research ships FRS *Africana* (May – July) and FRS *Algoa* for a series of cruises which commenced in April 1999 on the German vessel RV *Poseidon* and ended in August 1999 on FRS *Algoa* and the Namibian RV *Welwitchia*. The focus on these cruises was training of marine scientists and technicians from SADC countries and 60 trainees were given hands-on training. They came mainly from South Africa, Namibia and Angola, but also Kenya, Moçambique, Tanzania, the Seychelles and Malawi. A total of 15 M&CM tutors took part in these important capacity-building cruises off Angola, Namibia and South Africa. Namibia made RV *Welwitchia* available at short notice when FRS *Africana* developed propulsion motor problems in Angolan waters in late July, reflecting impressive political support for the entire initiative.

Good training can only take place if there is good research and an ambitious research programme was included investigating oceanographic conditions in the Angola-Benguela Front (ABF) region and the Benguela system under winter conditions. During winter, the ABF is at its most northerly position, whereas in the Benguela system there is a strong difference in conditions south of 30°S, where upwelling is suppressed by westerly winds. Disciplines covered included physical, chemical and biological oceanography and specific tasks such as ground-truthing of satellite imagery, acoustic stock assessment survey techniques and the distribution of pelagic and demersal fish in relation to the environment. Training on board consisted of formal lectures and hands-on training. Trainees were encouraged to make presentations regarding their work. This was followed by workshops ashore and presentations by trainees at the 10th Southern African Marine Science Symposium in Wilderness during November 1999.

The BENEFIT Research Training cruises also clearly put oceanographic and marine resource research in the public eye and on the political map in the three coastal countries with news briefings and official ministerial-level receptions being held during port calls in Walvis Bay and Luanda.

PUBLICATIONS

In 1999 M&CM research personnel were involved in 130 publications, oral papers and poster presentations. This total is slightly less than the 139 of 1998. The number of refereed articles however, marks a considerable decrease from last year, with 51 being produced in 1999 compared to some 70 in 1998. Of the 79 non-refereed publications produced, 43 constitute posters or oral papers presented at the 10th Southern African Marine Science Symposium (SAMSS 2000: Land, Sea and People in the New Millennium) held in Wilderness, South Africa during November 1999. A single issue, Volume 21, of the *South African Journal of Marine Science* was produced in 1999. The Journal continues to be well supported by both southern African and international scientists, with Volume 21 containing 30 contributions. It is encouraging that more papers from young southern African scientists are being processed by the Journal.

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